Larval characteristics of some fishes from the East Coast of Southern New Zealand

by

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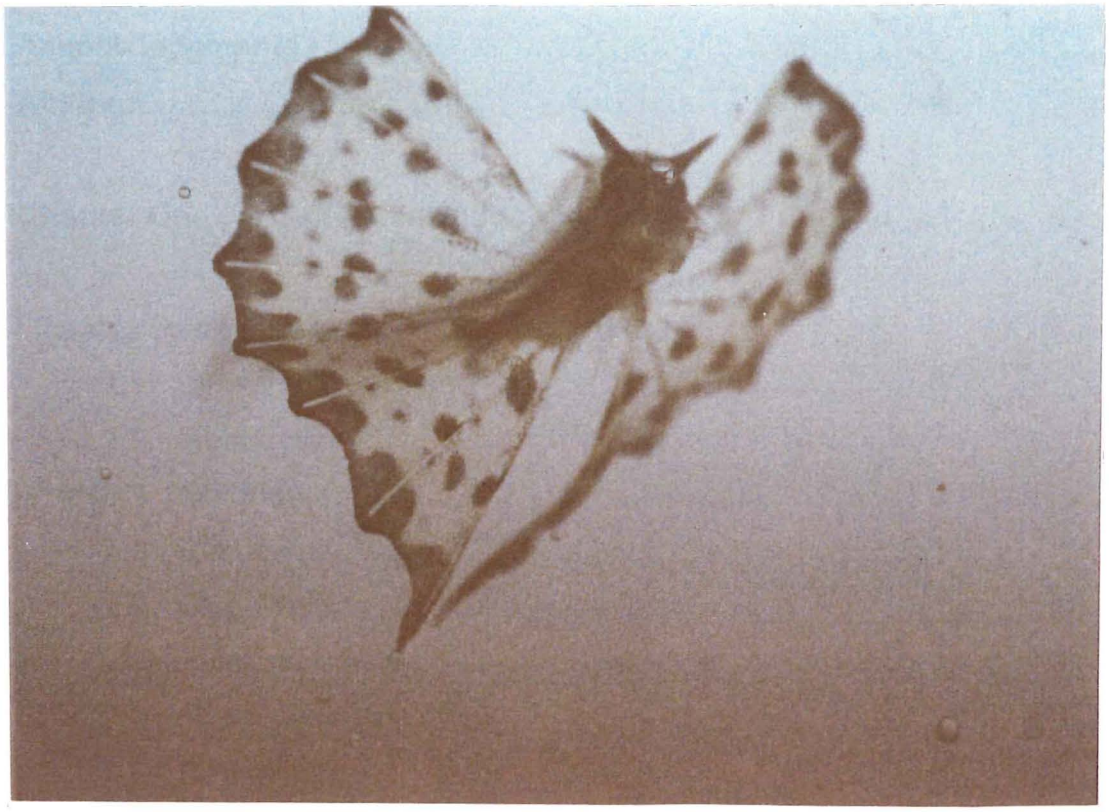

(Frontispiece: larval deepsea pigfish (*Congiopodus coriaceus*))

In the beginning God created the heavens and the earth. Now the earth was formless and empty, darkness was over the surface of the deep, and the spirit of God was hovering over the waters.

Genesis chapter 1, vs. 1&2

This thesis would not have been possible without the contributions of many people. In particular I would like to thank my supervisor Dr. David Schiel for arranging funding and equipment, keeping the project on the straight and narrow, and for his invaluable input into the writing of this thesis.

Special thanks must also go to Mike Hickford for allowing me to remove specimens from his samples, for the endless selection of music aboard the Tawaki, for enduring my grammar, and for his incomparable commitment to long-term, bathypelagic plankton sampling. It must be about time to check the catch by now Mike...

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Lastly, I wouldn't be here, or have a future hope, without my Lord and Saviour, Jesus Christ, to whom I owe a debt I can never repay.

The status of early life history descriptions for teleost fishes in New Zealand is low in comparison to other areas around the world. New Zealand itself is well-positioned to increase the number of teleost species that are known as larvae with species from subtropical, temperate, and sub-Antarctic waters being found within New Zealand's Excusive Economic Zone. Areas that have a high diversity of species are likely to be where different water currents converge.

Work on larval fishes in New Zealand has been predominantly focussed in northern New Zealand; an area of convergence between subtropical water and warm-temperate water. Relatively less work has been done in central and southern New Zealand. In particular, very little work has been done in the subtropical convergence zone on the east coast of the South Island.

Forty three species of larval fishes collected from Kaikoura are identified, described, and illustrated. Seventeen species (*Stokellia anisodon*, *Diaphus* sp., *Pseudophycis bacchus*, *Echiodon pegasus*, *Paratrachichthys trailli*, *Leptonotus elevatus*, *Helicolenus barathri*, *Scorpaena papillosus*, *Congiopodus coriaceus*, *Lepidoperca* sp A., *Taumakoides rua*, *Mendosoma lineatum*, *Grahamina capito*, *Grahamina signata*, *Gobiopsis atrata*, *Seriolella caerulea*, and *Colistium guntheri*) are previously undescribed as larvae, pre-juveniles or pelagic juveniles. Existing descriptive accounts for 14 other species are extended. Available information for each species is synthesised and referenced from both published and unpublished sources.

The status of early life history descriptions for New Zealand teleosts is discussed in relation to other geographical regions of the world. The need for plankton tows down to depths of several hundred meters, and also for intensive aquacultural facilities for rearing larvae from eggs, may mean that the availability of research vessels and aquaculture facilities may limit the extent to which larval fishes are known in New Zealand.

Identification of larval fishes can be very difficult as they may differ considerably from the adult form, but this is a vital part of understanding processes that influence future populations of fishes. Without the ability to identify larvae to species level, the resolution of studies on abundance and patterns of larval fishes is inadequate. This has important ramifications not only in understanding the full life histories of commercially important species, but also in understanding the ecology of near-shore species of fish. The timing and location of spawning areas, relationships with oceanographic factors (such as currents and water temperature), and methods of accurately estimating the age of larvae, are all based on a knowledge of species identification. With the help of these, it is possible to investigate larval dispersal patterns and mechanisms, growth and mortality rates of larvae, and possibly relate findings to future recruitment to adult populations.

To date, relatively few fish species have had their larval stages described in New Zealand, or elsewhere in the world. Most larval fish identifications have come from areas with a long history of commercially important fisheries such as the Northeast Atlantic and the Mediterranean Sea (Kendall & Matarese, 1994). Probably the most important single larval fish publication is Moser *et al.* (1984), which resulted from an international symposium of key researchers in larval fish taxonomy. Moser *et al.* includes information on over 20,423 fish species but only c. 1,932 of these are known as larvae, and another 726 as eggs.

Regional guides for larval fish identification exist for nine separate areas of the world (see Kendall & Matarese, 1984, for discussion and references). These are mostly coastal species; comparatively fewer oceanic species are described or illustrated as larvae. The only study with an exclusively oceanic emphasis was by Ozawa (1986) who described oceanic ichthyoplankton from the Northwest Pacific. Geographical areas for which very little is known about larval fish, even for coastal species, are the Pacific and Atlantic coasts of South America, the Atlantic coast of Northern Africa, New Zealand, and southern Australia. However, a guide which includes 125 species of larval fishes from Australia is currently in press (Neira *et al.*).

The only areas where greater than fifty percent of the fish species are described as larvae are the Northeast Atlantic, the Mediterranean, and the Antarctic (Fig. 1.1). Worldwide the average number of species known as larvae

proportion

is only 10% (Kendall & Matarese, 1984). Of the nine areas considered by Kendall & Matarese, the area closest to New Zealand (the Indo-Pacific) has the poorest percentage of larvae known (10%). It should be noted that this area is the most speciose of all the areas considered with 3921 species. However, this does not compare well to the second-most speciose area (Northwest Pacific) which has 34% of its 3500 species known as larvae.

New Zealand's geographical location is ideally suited for extending the current state of teleost early life history descriptions. As of 1989, over 923 teleost species are known from New Zealand's Exclusive Economic Zone (Paulin *et al.*, 1989) and this figure is likely to be a conservative estimate (Andrew Stewart, Museum of New Zealand, pers. comm.). Both warm-temperate and cool-temperate species are present around the New Zealand mainland, and subtropical species can be found in the far north (e.g., the Kermadec Islands (Francis, 1996)). Ocean currents from the southern ocean and eastern Australia, and warm subtropical currents in the north, all potentially bring species of larval fishes from very different ecological areas to New Zealand. Settlers of subtropical species have arrived as larvae, and survived to adulthood, on the Poor Knights Islands in years when the warm East Auckland Current has moved towards the islands (Doak, 1991; Francis, 1996). The result of this is a high diversity of species in sites where different currents converge.

Despite a good setting for larval fish research, there is no published guide to the many species of fish larvae found in New Zealand. In fact, larval fish descriptions and illustrations are rare in New Zealand's scientific literature. This is particularly evident when compared to values for the nine geographical areas for which a guide to larval fish is available (Fig. 1.1).

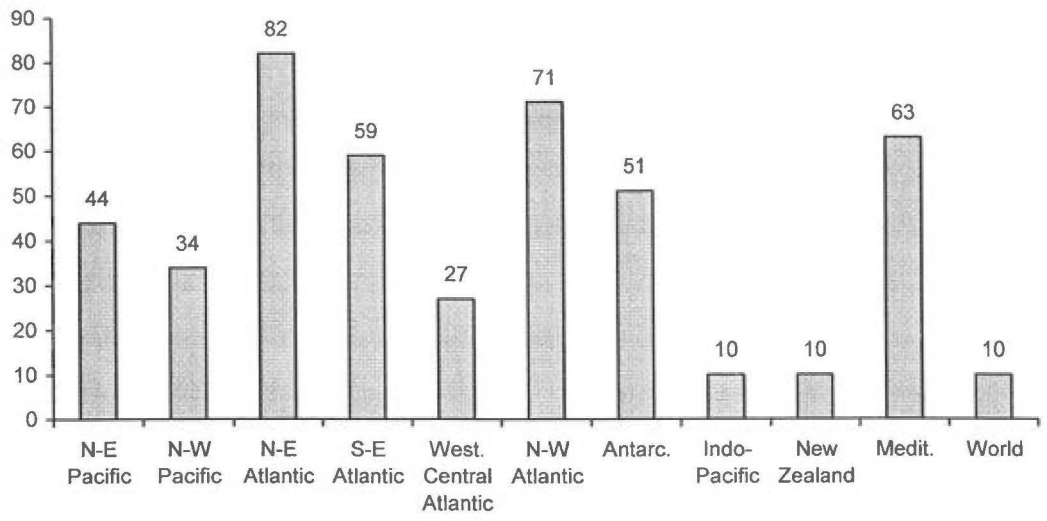

Figure 1.1 Percent of fish species known as larvae by geographic region (from Kendall & Matarese,1984).

The value for New Zealand is taken from all available published and unpublished sources and excludes species for which only eggs are known. Values from Kendall and Matarese (1984) use only published accounts that have sufficiently good illustrations and descriptions of larvae to enable a positive identification from a plankton sample.

Perhaps the most well known contributions to larval fish systematics from New Zealand are the accounts of congrid eel leptocephali (Castle, 1963; Castle, 1984; Castle and Robertson, 1974). These publications are particularly notable because these are larvae that travel great distances from their spawning grounds around Fiji to reach their adult habitats within New Zealand. Also of importance are publications by Crossland (1980, 1981, 1982) that provide several original descriptions and illustrations of larval fish species encountered in the Hauraki Gulf and east of Northland. Kingsford (Kingsford, 1985, 1988; Kingsford and Atkinson, 1994; Kingsford and Milicich, 1987), Regan (1916), and Roper (1981, 1986), have all made valuable contributions to early life history descriptions for some species. Publications by Cassie (1955, 1956) have also been useful, particularly for identifying snapper (*Pagrus auratus*) eggs and larvae. Kingsford (1988) reviewed the work from northern New Zealand and provided references to several relevant but unpublished theses.

Central New Zealand has probably had the least work published on larval fish. The exceptions are: Baker (1972, 1973), whose work is instrumental to current understanding of clupeid larvae, particularly sprats and pilchards (*Sprattus* sp.); McDowall (1964, 1965, 1978), who did much to identify the composition of the whitebait catch and other larval stage freshwater species; and Ruck (1971, 1973a, 1973b, 1980), who described the eggs of several intertidal species that lay demersal eggs. Yolk sac larvae and some later stages of these species are included in these publications.

The east coast of the South Island has had more work than central New Zealand but less than northern New Zealand. In the early part of the century, much of this work was based at the Portobello Marine Fish Hatchery (now Portobello Marine Laboratory). In particular, Anderton (1906) was the first to describe and illustrate red gurnard (*Chelidonichthys kumu*), brill (*Colistium guntheri*), and common sole (*Peltorhamphus novaezeelandiae*), as eggs and larvae. Graham (1939, 1956) provided information on spawning times for 34 species of teleost fishes, as well as descriptions or illustrations of eggs and larvae of seven species. More recently some important publications from Robertson (Robertson & Raj, 1971 (sand flounder *Rhombosolea plebeia*); McDowall & Robertson, 1975 (Galaxiidae); Robertson 1975a (planktonic eggs), 1975b (Carapidae), 1976 (*Maurolicus muelleri*); Robertson & Mito, 1979 (barracouta *Thyrsites atun*, lanternfish *Gymnoscopelus piabilis*, pigfish *Alertichthys blacki*, rockling *Gaidropsarus novaezelandiae*, snipefish *Macrorhamphosus scolopax*, thornfish *Bovichtus variegatus*); Robertson, 1980a (frostfish *Lepidopus caudatus*); Robertson, 1980b (planktonic eggs); Grimes & Robertson, 1981 (silver warehou *Seriolella punctata*)) have served to increase the knowledge of larval fish and eggs in New Zealand.

Although the extent of published work on larval fishes in New Zealand is limited, there is a large amount of information in unpublished theses (e.g., McDowall (1963), Elder (1966), Robertson (1973), Ruck (1976), Frentzos (1980), Thompson (1983), and Kingsford (1986)), and in Fisheries Research Bulletins produced by the New Zealand Ministry of Agriculture and Fisheries, or in local journals such as Victoria University of Wellington Zoology Publications. Also, two unpublished portfolios of illustrations of larval fishes exist. One of

these (Roper, 1981) contains illustrations made by Roper from his work on larval fish in the Whangateau Harbour in North Auckland. The other (Kingsford & Barrington, 1986) incorporates many of Roper's (1981) illustrations.

Areas of ocean where different currents meet or converge are likely to contain a high diversity of larval stage organisms. Larval fish in areas of convergence in the north of New Zealand (such as east of Northland where the East Auckland Current terminates) have been relatively well investigated compared to other areas of convergence in New Zealand. In particular, the southern convergence of southward-moving warm-temperate water, and northward-moving cool-temperate water, off the east coast of the South Island (Heath, 1971) has had very little work done. The exceptions are unpublished research on annual cycles of plankton (Grieve, 1966), distribution and abundance of tarakihi (*Nemadactylus monopterus*) eggs near Kaikoura (Robertson, 1973), and some offshore plankton tows at stations above the Chatham Rise (Robertson & Mito, 1979).

The purpose of my study is to expand the descriptions of larval fishes found near Kaikoura, which is near the location of the southern convergence zone. In particular, my aims were to identify and illustrate previously unknown larval stage fishes, as well as extending the descriptions available for species previously identified but not fully described throughout their early life history.

2.1 DEFINITION OF TERMS

Terminology used in describing developmental stages of ichthyoplankton varies from author to author (for example, Ahlstrom *et al.*, 1976; Balon, 1975). Kingsford (1988) notes that development is a continuous process and that splitting this into discrete stages is not always easy or appropriate. He states that "it is crucial for investigators to define their terminology," and concluded that "A terminology should be used that best fits the type of fish being studied."

The present study encompasses a large diversity of fishes and any one rigorously defined system of terminology will not suit all species equally well. Kingsford and Choat's (1985, 1986) system of calling fish (from hatching to life as a juvenile) 'small fish' solves this problem but is ambiguous in that some species of fish are small when adult. Kingsford and Milicich (1987) used the term "pre-settlement fish" to indicate leatherjacket (*Parika scaber*) specimens that were not yet settled into juvenile habitat. However, this would be very difficult to apply rigorously in pelagic species such as yellow-eyed mullet (*Aldrichetta forsteri*) where the concept of settlement is indistinct. Also, Leis (1993) warns against confusing ecological terms (e.g., pre-settlement) with morphological ones (e.g., larva, metamorphic). Lastly, use of the words 'larval fishes' is very widespread in the international literature. Even if the strict interpretation of those words varies from paper to paper, invariably they refer to a period in the early life history of fishes and are probably more useful than any other suggested terminology. Accordingly, the terms used in this study to describe development of fishes, from hatching to life as a juvenile, are only loosely applied and are not intended to be tightly definitive stages:

- Larval fishes / Fish larva(e) -general terms which encompass the early life history of fishes from hatching to life as a juvenile.

- Yolk-sac larva(e) -From hatching until yolk-sac absorption is complete.

- Larva(e) -from yolk-sac absorption until a juvenile form is attained (including fin numbers and position, eye position in pleuronectids, but excluding pigmentation). Flexion occurs during this stage of development.

- Pre-juvenile(s) -after a juvenile form is attained (including fin numbers and position, eye position in pleuronectids, but not pigmentation) but prior to settlement. In pelagic species this is purely a subjective assessment.

Some overlap may occur between terms particularly between "larva" and "pre-juvenile". The modifiers "early stage" or "late stage" simply refer to the early part of a given stage of development or the late part of a developmental stage, respectively. Thus, a "late stage larva" would be bordering on pre-juvenile status while an "early stage larva" is likely to have just completed yolk-sac absorption.

Abbreviations used in the text are as follows:

- TL - Total length as measured when specimen is dead or preserved (i.e., after shrinkage).
- TLL - Total live length (total length measured when specimen is still alive).
- VL - Length of vexillum in carapid larvae
- SL - Standard length
- FL - Fork Length
- BD - Body Depth

All terminology for describing the head spination of larval scorpaeniformes follows that of Moser & Ahlstrom (1978).

2.2 INTRODUCTION

Fish larvae are usually identified by obtaining several specimens of varying sizes with similar morphologies. These are usually collected over a short period of time and near the same place. From these individuals a developmental series is created. The species identity is then established from the largest specimens, if possible. If the largest stage caught is not identifiable, then it is sometimes possible to compare the unknown species with larvae of another known species, and thus place the unknown specimens within a particular family. Then, if members of that family are known to inhabit the area and spawn at the appropriate time, it may be possible to appoint a presumptive identification based on that information. This process has a lot of scope for error.

An alternative method is to capture eggs, or early stage larvae, and artificially rear them until a recognisable stage is reached. This method is logistically more difficult because larval fish are extremely delicate and require very high water quality and live foods such as rotifers or brine shrimps. The feeding requirements of larvae may also change as they grow. Small larvae may be incapable of ingesting brine shrimp nauplii, for instance, and require smaller zooplankton prey such as rotifers. As the larvae grow, the preferred size of their prey may increase. The fragile structure of larval fishes makes it difficult to capture live larvae without damage. Using light traps instead of plankton nets is an option. However, large crustacea that are also attracted to the light often eat or damage captured fish larvae. In addition, not all species of larval fish are attracted to light and some early stage larval fish cannot actively swim toward the light.

Identifying larval fish from developmental series, derived from wild caught specimens, is subject to error through confusing a particular larval fish with another similar species. Also, if more than one species with similar larvae is spawning there is potential for the two or more larval species to be combined into one developmental series. Laboratory rearing ensures that species identification is correct, but can have problems with wild-caught larvae differing morphologically from laboratory-reared larvae.

Lastly, the question of how best to display developmental series must be addressed. Photographs are a useful guide while sorting plankton samples, and are relatively quick and easy to produce. Line drawings, in comparison, are subjective and time-consuming to produce. Several works in New Zealand use a photographic record alone to describe the larval fishes mentioned (eg. Frentzos, 1980; Thompson, 1983; Cole, 1987). However, photographs are usually regarded as inadequate, unless accompanied by accurate line drawings that show features that are not clear in the photographs (Leis, 1993). Photographs can be unclear or, at worst, misleading. An example of this is a photograph of a larval butterfish, *Odax pullus*, (Ritchie, 1969), which was later used to construct a line drawing of this larva in Kingsford & Barrington (1986). The result was that the posterior edge of some finfold pigmentation was confused with the posterior edge of the finfold itself. This caused the shape of the larva to be greatly misrepresented in the drawing. Also, photographs do not reproduce well during photocopying, and since theses cannot be obtained as reprints this limits their usefulness for identification purposes by other workers. Leis (1993) suggests a guideline for published larval fish descriptions that includes:

- Depositing specimens in a reference collection
- Making good quality, accurate line drawings
- Having a detailed written description of development and key morphological features
- Having a section on how identity was established.

Accordingly, this study attempts to incorporate the suggestions of Leis (1993), and line drawings have been made in preference to using photographs. The phylogenetic order of species in this work is based on that of Paulin *et al.* (1989). Common names of most species are from Paulin *et al.* (1989), but those of some tripterygiids that are not included in Paulin *et al.* (1989) are from Fricke & Roberts (1993).

2.3 METHODS

Larvae were primarily collected by towing a plankton net of box-pyramid design (mouth dimensions 707 x 707 mm, mesh area $6m^2$, mesh size 280 μm) alongside a 6m runabout. The net was towed so that the top edge of the mouth was c. 10cm above the water surface ('surface tows'), c. 1m below the surface ('one meter tows'), or c. 3m below the surface ('three meter tows'). Tow speeds averaged 6.1 kmh^{-1} at the surface, 4.5 kmh^{-1} at one meter depth, and 2.6 kmh^{-1} at three meters below the surface. These tows were primarily of 15 minutes duration and were part of a quantitative study of larval fish distribution and abundance around the Kaikoura region (Hickford, PhD in progress). Some tows of shorter duration were done in an attempt to capture larvae without damage.

A second plankton net was used briefly in the summer of 1996/1997 to sample immediately below surface slicks (Kingsford & Choat, 1986). This net had a smaller mouth (316 x 316 mm, mesh area $1.5m^2$, mesh size 280 μm) and was attached to a long pole. This allowed tows to follow slick lines more closely than had been possible with the larger net.

Light traps suspended over rocky reef habitat at night were also used to capture larval fish. These proved most successful in shallow reef environments where tripterygiid pre-juveniles dominated the catch. The light traps attracted large numbers of invertebrates and it is possible that some predatory arthropods devoured many of the captured larval fishes. Partially eaten remnants of larval fish were seen. Larvae were also successfully caught by shining a light onto the water, and capturing fish larvae with a dipnet or bucket as they approached the light. This proved to be the most successful method of capturing live specimens of fragile larvae such as smelts (*Stokellia anisodon*).

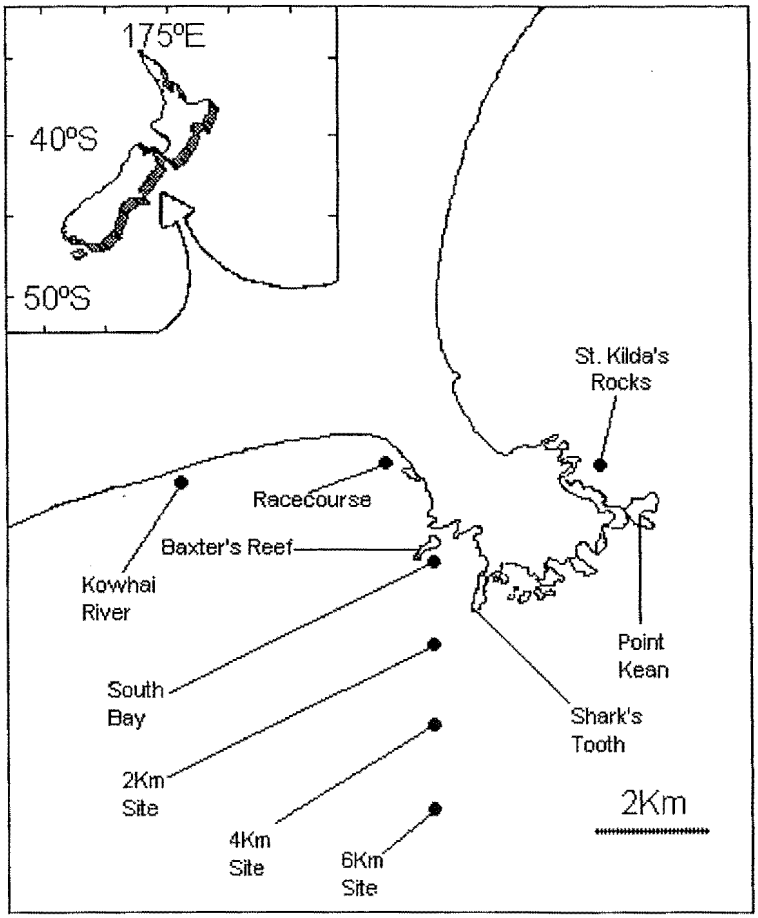

Figure 2.1 Map of the Kaikoura peninsula showing study sites (•)

Study sites were primarily in 5 locations. On the northern side of the Kaikoura peninsula some plankton tows were made in the summer of 1995/1996 just east of St. Kilda's rocks. However, most sampling was done on the southern side of the peninsula. In particular, four sites were sampled every two weeks from October 1995 - February 1997 ('transect sites'). The first of these sites was in South Bay immediately on the seaward side of Baxter's reef. This site was sheltered from prevailing onshore winds and consequently many more plankton tows were performed at this site than anywhere else. The depth of water at this site was c. 17m. The remaining three sites, also sampled bi-weekly, fall on a line running due south from Baxter's Reef and are 2 km, 4 km, and 6 km distant from land respectively. Water depths at these sites are (approximately) 52m, 81m, and c. 1200m. Lastly, samples were also taken in close proximity to a fine shingle beach that extends from opposite the

racecourse to past the mouth of the Kowhai River (5 km south of Kaikoura). Some samples were taken from opposite the river mouth, and others were taken from the northern end of the beach (opposite the racecourse). Water depths were typically 5 - 10m when sampling near the beach.

Immediately following capture, live larvae were separated from the rest of the plankton and placed in a 10L bucket of fresh seawater for the return journey to the laboratory. Dead larvae were not separated until the plankton samples were transferred from the sample tubes into larger storage containers, and preserved in 2% buffered formalin. Most larvae were dead upon removal from the net. Live larvae were returned to the laboratory and kept in shallow containers (12L capacity, 300 x 300 x 150 mm) with a constant supply of fresh seawater (filtered to 75 μm). These containers were used during the summer of 1995/1996 and up until October 1996.

Two aquaria (750x300x450 mm) were used to hatch eggs, and to rear larvae during the summer of 1996/1997. These were kept at ambient sea temperature by immersion in a water bath of fresh running seawater, and aerated by a wooden air-diffuser. Ten percent of the water was siphoned out daily and fresh, filtered (5 μm) seawater was added. The aquaria were illuminated by a single 100W incandescent light bulb suspended above them. Light/dark cycles of c. 14:10 hours were maintained. Experience from the previous summer suggested that larval fish require greater water depth than was available in the shallower containers. However, late stage larvae and pre-juveniles were able to be maintained for long periods of time in them.

Great difficulty was experienced in returning larvae to the laboratory alive, even if the larvae appeared healthy immediately after capture and the time interval from capture to returning to the laboratory was not large. It is thought that capture-related stress, physical damage during capture, and post-capture stresses (e.g., vibration of the boat and temperature variability), all contributed to this mortality.

Larval fishes were fed on a diet of rotifers (*Brachionus plicatilis*) and brine shrimp (*Artemia salina*). These had been reared on a culture of green algae (*Isochrysis tahitian* sp.) which was grown in serial culture (using Guillard's f/2 seawater medium with a 100W metal-halide light source). Rotifer densities were

maintained at 1-10 per mL in the larval fish rearing tanks. This was achieved by straining rotifers out of the parent cultures with a 30 μm filter, and replacing rotifers lost through feeding by larval fishes, starvation in the absence of microalgae, or during the daily water changes. *Artemia* nauplii were added as fish larvae increased in size but were largely ignored by the larvae. Densities of these varied from 1 - 4 L^{-1}, but the phototactic behaviour of these larval crustaceans resulted in highly clumped distributions within the aquaria (even with water turbulence caused by the air-diffuser in the aquaria). Larger larvae and pre-juveniles were fed on a mixed diet of late instars of *Artemia*, whiteworms, mosquito larvae, and palletized fish food.

Where possible, larvae were kept alive and ongrown to a recognisable stage. Drawings were made using a Wild dissecting stereomicroscope with a *camera lucida* attachment. Live larvae were anaesthetised before being drawn by placing a few grains of benzocaine in a watchglass of seawater with the larvae. Small larvae (<6 mm TLL) could usually be anaesthetised and drawn without ill effect. However, larger larvae did not recover from the anaesthetic, suggesting that dosage may be more critical in larger fish larvae.

Specimens were preserved in 2% buffered formalin until mid-1996. Thereafter, new specimens were preserved directly in 95% ethanol to prevent otolith dissolution. A reference collection of specimens is deposited at Edward Percival Field Station, Kaikoura.

2.4 RESULTS

Table 2.1 Summary of ichthyoplankton identified in this study (order of species after Paulin *et al.* (1989)).

Species	Yolk-Sac Larvae	Larvae	Pre-juveniles	Pelagic Juveniles
*Sprattus muelleri**		✓	✓	
*Stokellia anisodon**		✓	✓	
*Diaphus sp.**		✓		
Gymnoscopelus piabilis		✓		
*Pseudophycis bacchus**				✓
Auchenoceros punctata		✓	✓	
Gaidropsarus novaezelandiae		✓	✓	✓
*Echiodon pegasus**		✓		
Eurypleuron owasianum	✓			
Trachelochismus melobesia		✓	✓	
*Paratrachichthys trailli**	✓	✓		
*Leptonotus elevatus**			✓	
Hippocampus abdominalis			✓	
*Helicolenus barathri**		✓	✓	
*Scorpaena papillosus**			✓	
*Congiopodus coriaceus**		✓	✓	
Chelidonichthys kumu	✓	✓	✓	
*Lepidoperca sp. A**	✓			
Acanthoclinus fuscus		✓	✓	
*Taumakoides rua**			✓	
*Mendosoma lineatum**	✓			
Aldrichetta forsteri		✓	✓	✓
Notolabrus celidotus		✓	✓	
Odax pullus	✓	✓		
Bovichtus variegatus		✓	✓	✓
Genyagnus monopterygius	✓	✓	✓	
Parapercis colias		✓		
Forsterygion lapillum		✓	✓	
*Grahamina capito**		✓	✓	✓
*Grahamina signata**	✓			
Gilloblennius tripennis		✓	✓	
Notoclinus fenestratus		✓	✓	
Ruanoho decemdigitatus		✓	✓	
Grahamichthys radiata	✓			
*Gobiopsis atrata**			✓	✓
Thyrsites atun		✓	✓	
*Seriolella caerulea**			✓	
Arnoglossus scapha		✓		
Colistium guntheri		✓		
Peltorhamphus novaezelandiae		✓	✓	
Rhombosolea plebeia		✓	✓	
Rhombosolea retiaria		✓		
Parika scaber			✓	

* denotes a previously undescribed species

2.5 Order Clupeiformes

Family Clupeidae

Sprattus muelleri (Hector) **Stout Sprat**

Historically, only one species of sprat (*Sprattus antipodum*) was known to be present in New Zealand. A revision of the genus Sprattus by Whitehead *et al.* (1985) revealed that another species, *Sprattus muelleri*, is also present. This differs only in small details such as the shape of the tooth-bearing pad on the tongue, body depth/length ratio, and striations on the posterior margin of the scales. It is unlikely that these species differ greatly at a larval stage and so may be indistinguishable until late in juvenile life.

Baker (1973) illustrated the full development of *Sprattus antipodum.* Spawning times for *S. antipodum* are from May to November in the Marlborough Sounds (Baker, 1973) and July - January off the Otago coast (Robertson, 1980). Crossland (1981) found sprat eggs in the Hauraki Gulf to occur sporadically in time and space, and only in small numbers. His largest catch of sprat eggs occurred in October 1975. He believed it was unlikely that sprats spawned over the winter months during the time of his study as no larvae or pre-juveniles were captured. It is possible that early stage larvae of sprats were misidentified as *Sardinops neopilchardus,* as there remains no means of separating them below c. 25 mm total length.

Current work on sprats off the Otago coast suggests that *S. muelleri* is the most common species in coastal waters, with *S. antipodum* being found mainly in sheltered coastal waters such as Otago Harbour (Ardern, pers. comm.). If this is true around New Zealand then it is likely that the species described by Baker (1973) and Crossland (1981) is *S. antipodum,* and that described by Robertson (1980) is *S. muelleri.* Adult specimens collected in plankton tows at night, in South Bay were *Sprattus muelleri.*

Larval specimens in this study (Ref. Collection. AN) were obtained by plankton tows at the surface around the Kaikoura Peninsula, mainly during the summer months (November - February) of 1995/1996 and 1996/1997. Specimens caught by plankton net proved extremely fragile and were dead, or dying, upon removal from the net. These were identified by comparison to

illustrations in Kingsford & Barrington (1986) and Baker (1973), and by the presence of *S. muelleri* juveniles and adults.

Larval sprats have an elongate body shape. They are mostly transparent in life (milky white in formalin or alcohol) with black melanophores arrayed regularly along the ventral gut surface. Sprats hatch at c. 4 mm (cf. Baker, 1973), with dorsal and anal fins appearing by 9 mm (Fig.2.2 a). Flexion occurs between 9 mm and 12 mm (Fig 2.2 b) and the pelvic fins appear along the pyloric section of the gut at approximately 19 mm (Table 2.2). The body begins to deepen after about 31 mm. More melanophores begin to appear on the dorsal midline posterior to the origin of the dorsal fin, and also along the posterior third of the lateral line. These become smaller and more numerous as they extend forward during development, until metamorphosis is complete. Larvae and pre-juveniles are not distinguishable from those of *S. antipodum* until a size of c. 50 mm TL is attained and development of the tongue is complete. The absence of striations on the posterior margin of the scales is the best indicator of species until this size is reached.

Table 2.2 Meristic counts and features used in identifying *S. muelleri.*

	Dorsal	Anal	Adipose fin present?	Pelvics appear at	Dorsal and anal fins overlap?
Larvae	15-16	14-18	no	c.19mm TL	no
Adults*	16	18	no	-	no

*for *S. antipodum* (from Ayling & Cox, 1987)

Larval sprats superficially resemble other species such as pilchards (*Sprattus neopilchardus*), anchovy (*Engraulis australis*), smelts (*Retropinna retropinna*), and Galaxids. They can be distinguished from pilchards by having only a single row of melanophores along the ventral surface (cf. a double row in pilchards), and from anchovy, smelts, and Galaxids, in which dorsal and anal fins overlap vertically (sprats' dorsal and anal fins do not overlap). Unlike sprats, smelts have an adipose fin (visible after 14 mm) and do not develop pelvic fins until around 25 mm (cf. 19 mm in sprats).

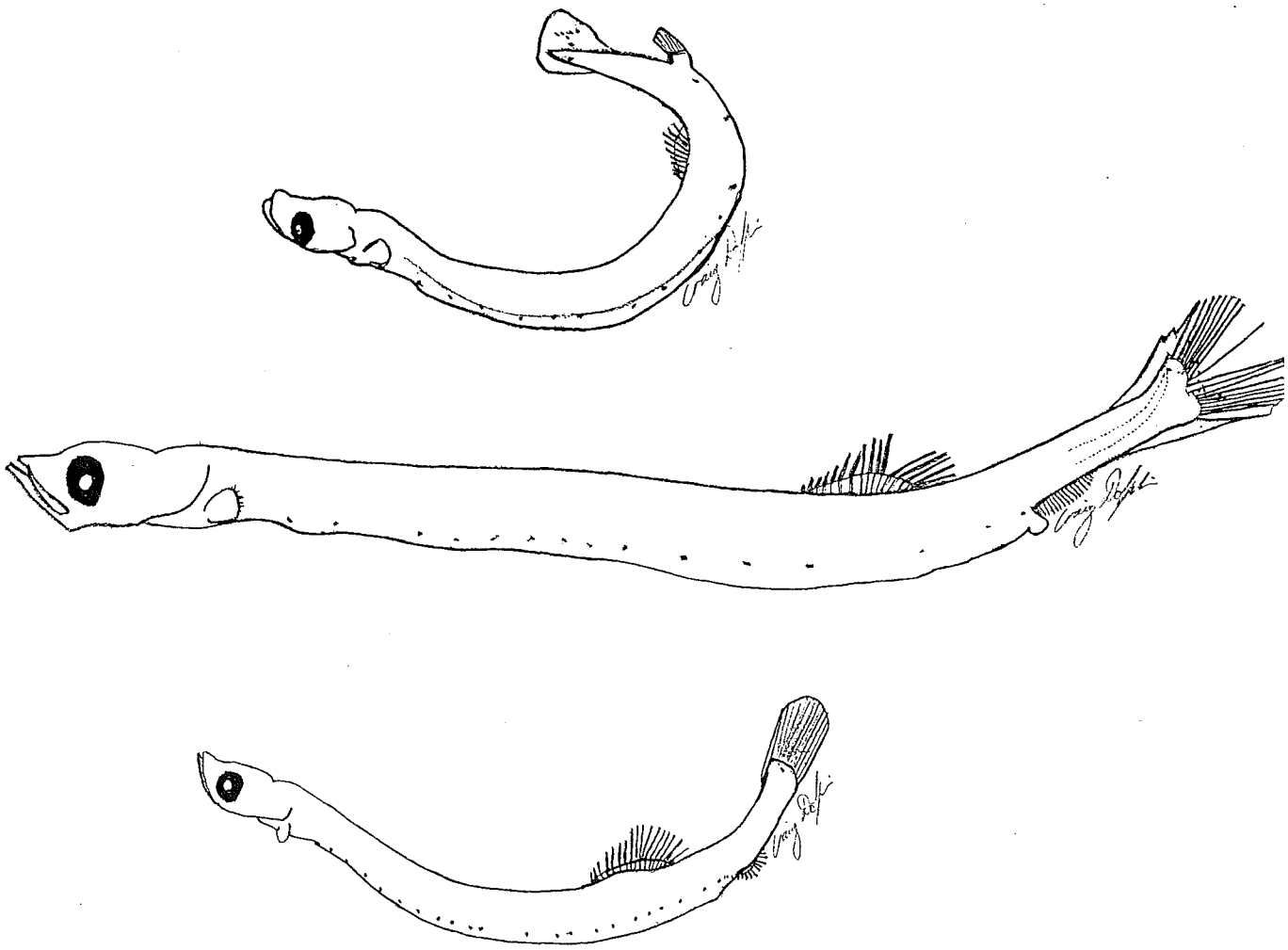

Figure 2.2 Partial development of slender sprat (*Sprattus muelleri*)
(scale = 1 mm)
a) Total Length 9.0 mm
b) Total Length 15.5 mm
c) Total Length 17.8 mm

2.6 Order Salmoniformes

Family Retropinnidae

Stokellia anisodon (Stokell) **Stokell's Smelt**

Smelts are marine fishes which migrate into freshwater to spawn. The family Retropinnidae consists of four species with two endemic species present in New Zealand (*Retropinna retropinna* and *Stokellia anisodon*), and two in Australia (*R. semoni* and *R. tasmanica*).

Smelts deposit demersal eggs above estuaries, and the larvae are swept out to sea after hatching (McMillan, 1961; McDowall, 1978, 1979). Eggs of *Stokellia anisodon* are reported to be 0.8 mm in diameter and take 2-3 weeks to hatch in freshwater. Size at hatching is c. 5 mm and larvae are washed out to sea (McMillan, 1961).

McDowall (1965) contains an illustration of a c. 46 mm TL *R. retropinna*, but otherwise larvae of New Zealand smelts are undescribed. McMillan (1951) reported capturing several adults and post-larvae of *S. anisodon* from Menzies Bay, Banks Peninsula, at night with the aid of a strong light. Smelts have occasionally been misidentified as galaxid larvae (McDowall & Robertson, 1975).

Larval smelts in this study (Ref. Collection AK, CG) were identified by fin ray counts, branchiostegal ray counts, and the structure of the upper jaw in the largest individual (Table 2.3). This individual was grown in captivity to a size of 51 mm TL from c. 35 mm TL over a period of 2 months. Specimens were caught in plankton tows from late January through to March, of 1996 and 1997. They were drawn alive and anaesthetised with benzocaine where possible. Exceptions to this were the first and last illustrations in the developmental series (Fig. 2.3 a&e) which were both preserved in 95% ethanol. No smelt larvae smaller than 9.8 mm TL were captured during this study.

Table 2.3 Meristic counts and features used in identifying *S. anisodon*.

	Dorsal	Anal	Branchio-stegal rays	Teeth only on premaxilla?	Adipose fin present?	Pelvic fins appear at	Dorsal and anal fins overlap
Larvae	10-13	17-18	2	yes	yes	c.25mm TL	yes
Adults*	11-12	19-22	2	yes	yes	-	yes
*Retropinna retropinna**	10-13	17-21	2	no	yes	?	yes

* from McDowall, 1978

Larval smelts superficially resemble sprats, pilchards, anchovy, and galaxids, and their development is also similar, with pelvic fins not appearing until late in the larval stage. They are highly elongated in body shape and are transparent, with dark melanophores present along the dorsal surface of the gut. Flexion has already occurred in the smallest individuals taken in this study (9.8 mm TL; Fig. 2.3 a). The anus is situated much closer to the tail than the head, and dorsal and anal fins are not well formed until a total length of 11 - 13 mm is attained. These structures first appear at approximately 10 mm TL with the finfold becoming increasingly constricted around the caudal peduncle, and muscle buds appearing at the base of the unformed dorsal fin rays. As the fin fold constricts further around the caudal peduncle, a small remnant is left which gives rise to the adipose fin. This is often difficult to see in preserved specimens as it is prone to lying flat against the dorsal surface of the animal (or else being mistakenly identified as a piece of skin flaking off the body).

The adipose fin is usually present by 14 mm TL (Fig. 2.3 b) although it may still be joined to the caudal fin. At this stage, the dorsal and anal fin rays are well formed with counts of 10 - 13, and 17 - 18, respectively (Table 2.3). These counts are more similar to *R. retropinna*, but examination of the upper jaw showed that teeth were only present on the premaxilla, and that the alveolar process of the premaxilla extends most of the way down the maxilla. McDowall (1978) states that this feature is absolutely diagnostic for this species.

The pelvic fins arise along the pyloric region of the gut but do not appear until a length of approximately 25 mm TL (Fig. 2.3 c) is attained. In contrast to the development of sprat, anchovy, and pilchard, no appreciable deepening of

the body is evident up to 51 mm TL (Fig. 2.3 e). This could, however, be an artefact of laboratory conditions for the single individual reared to this point. This seems likely given that mature specimens are entering freshwater when as small as 70 mm TL, and that the species only attains a size of 91 mm TL (McMillan, 1951). No larvae larger than 38 mm TL (Fig. 2.3 d) were captured in plankton tows during this study, and the relative body depth of these had not yet begun to increase.

Larval smelts can be separated from sprats, pilchards, anchovy, and galaxids, by the presence of an adipose fin for specimens longer than 15 mm TL. Below this length, the presence of a lateral-line serves to distinguish smelts from anchovy. Sprats and pilchards do not have overlapping dorsal and anal fins, galaxid larvae have dorsal and anal fins that are directly opposite, but the smelt's anal fin-origin lies between the midpoint and posterior margin of the dorsal fin.

No larval stage *R. retropinna* were recognised in this study but it is probable that developmental differences are minimal.

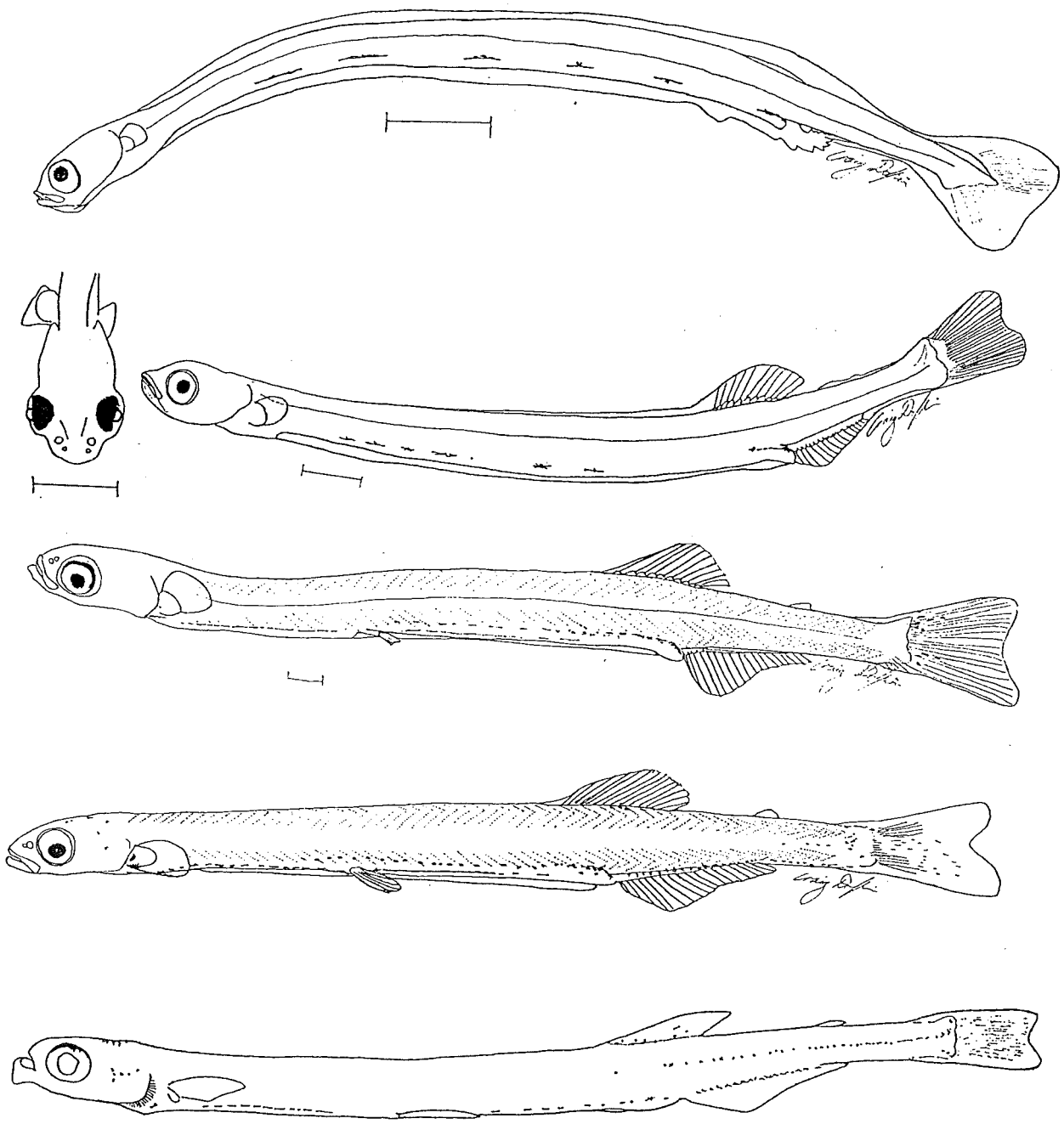

Figure 2.3 Development of Stokell's smelt (*Stokellia anisodon*)

(scale = 1 mm)

a) 10.5 mm TL

b) 14.8 mm TL

c) 27.7 mm TL

d) 38 mm TL

e) 51 mm TL

2.7 Order Myctophiformes

Family Myctophidae (Lanternfishes)

Lanternfishes are a widespread group of mid-water fishes found in all oceans. They are characterised by the presence of photophores that are often used in their classification. According to Paulin *et al.* (1989) there are 93+ species of Myctophids in New Zealand, which include at least 24 species of *Diaphus* and 5 species of *Gymnoscopelus*. Also, more species have been described from New Zealand since then (Nafpaktitis, 1995; A. Stewart, pers. comm).

The larval stages of Myctophids have been described from various parts of the world and a review of much of the information available can be found in Moser *et al.* (1984). Most Myctophids hatch at approximately 2 mm TL and all genera develop the middle branchiostegal photophore (Br_2) first (with the exceptions of *Notolychnus* and *Taaningichthys*)(Moser *et al.*, 1984).

Subfamily Lampanyctinae

Tribe Diaphini

Diaphus sp.

Diaphus specimens taken in this study (Ref. Collection AZ) were collected from South Bay in daytime plankton tows one meter below the surface, during October 1996. These were identified to genus level by the presence of a sub-orbital photophore, fin ray counts, gill raker counts, and eye shape of the largest individuals (compared to meristic values given in Moser *et al.* (1984, pg 221, Table 60; Table 2.4)). Identification to species level proved impossible from individuals collected as none were alive upon removal from the net. Furthermore, this genus is "among the most difficult to identify to species level" (Olivar and Beckley, 1995) from larval characteristics. However, this species can be placed within the 'moderately slender' (c.f. 'moderately deep') morphotype suggested by Moser & Ahlstrom (1972, 1974) and Moser *et al.* (1984), and reinforced by Olivar & Beckley (1995), for this genus. This is based upon body shape (slender bodied), and post-anal ventral-midline pigmentation patterns (series of numerous melanophores on post-anal ventral midline). This

species differs from the *Diaphus* sp. illustrated by Regan (1916) which fits the 'moderately deep' morphotype.

Superficially these larvae resemble both Tripterygiid larvae and *Gymnoscopelus piabilis* larvae, but can easily be distinguished by the presence of a sub-orbital photophore (So). The positioning of the anus at approximately mid-body also distinguishes Diaphus sp. from triplefins (where the anus is usually anterior to the mid-point of the body). The existence of c. 5 prominent melanophores along the dorsal-midline, and c. 5 along the ventral-midline, of the caudal peduncle seems characteristic of this species. In contrast to *Gymnoscopelus piabilis*, there is usually no pigmentation above the brain. Also, *G. piabilis* appears to have a smaller eye, relative to head length, than *Diaphus* sp.

In the smallest specimen collected (Fig. 2.4 a) the sub-orbital photophore is very difficult to see but the specimen can still be distinguished by the position of the anus. Flexion has not yet occurred. The finfold around the body is constricted dorsally around the caudal peduncle, and the anal fin and caudal fin is completely separated. The beginnings of caudal rays are also visible. Post-anal pigmentation is present on the dorsal and ventral midlines of the body, with several particularly prominent melanophores on the dorsal-midline. Around 15 small melanophores are present on the ventral-midline. A prominent melanophore is visible on the dorsal surface of the gut immediately adjacent to the anus. Less prominent is another melanophore, also on the dorsal surface of the gut, but in the region of the swimbladder. Another two melanophores are found on the dorsal-midline on the nape of the neck. No pelvic fins are present at this stage.

By 10 mm (Fig. 2.4 b) the sub-orbital photophore is highly prominent and flexion has occurred. Also, paired pelvic fins have appeared at approximately mid-gut. By this stage both dorsal fins are well separated, and fin rays are visible in both of the dorsal fins and the anal fin (Table 2.4).

Table 2.4 Meristic counts of *Diaphus* sp.

	First Dorsal	Anal	Pelvic	Gill Rakers
Moser *et al.* (1984)	10-19	11-19	8	4-11+9-21
This Study	12	18	8	4+11

The post-anal dorsal melanophores are grouped together on the anterior part of the caudal peduncle forming a distinctive dark patch. Similarly, the numerous small ventral melanophores on the post-anal ventral midline have become reduced to approximately 5 prominent melanophores. These are grouped directly behind the anal fin and form a dark patch directly opposite the dorsal patch. Another prominent melanophore can be seen on the dorsal part of the caudal fin close to the terminus of the caudal peduncle. Thickening of the body wall has reduced the visibility of the melanophores on the dorsal surface of the gut.

The largest specimen caught was 11.3 mm TL (Fig. 2.4 c) and the only apparent change is a slight increase in the length of the pelvic fins. No other photophores are evident at this size. The apparent absence of the middle branchiostegal photophore (Br_2) may be an artefact of the opacity of the larvae after preservation in alcohol.

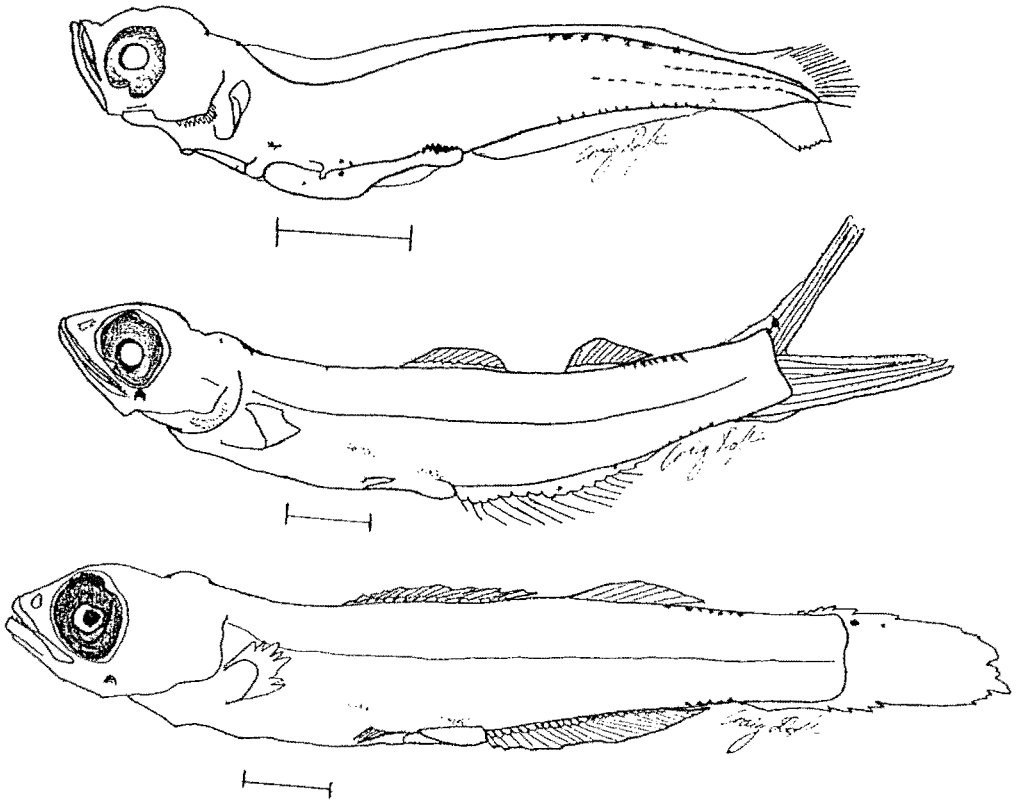

Fig.2.4 Development of *Diaphus* sp.

(scale = 1 mm)

a) 5.9 mm TL

b) 10.2 mm TL

c) 11.3 mm TL

Subfamily Lampanyctinae

Tribe Gymnoscopelini

Gymnoscopelus piabilis (Whitley)

The only available information on this species is found in Robertson and Mito (1979), who captured this species in surface-water plankton tows above the Chatham Rise, Pukaki Rise and Campbell Plateau, from December 1977 to mid-February 1978.

In this study, *Gymnoscopelus piabilis* specimens were captured in daytime plankton tows at the 2 km site during mid-October 1996. These tows were at a depth of 1m below a drift line. As with *Diaphus* sp., all individuals were dead upon removal from the net. These were subsequently preserved in 95% ethanol (Ref. Collection AU) before being measured and drawn. No larvae smaller than 10.5 mm TL, or larger than 22.2 mm TL, were captured during this study.

Individuals were identified as *G. piabilis* from illustrations in Robertson & Mito (1979). This identification was further supported by meristic counts from the largest individual captured. These fit well (except for gill raker counts that may not have developed fully) with the range of values given for the genus *Gymnoscopelus* by Moser *et al.* (1984; pg 221, Table 60). Fin ray counts (except from the pelvic fins) from the largest individual illustrated in Robertson & Mito (1979) also fall within the appropriate ranges (Table 2.5). However, this identification can only be certain to the generic level and these larvae may, in fact, be any of the *Gymnoscopelus* species present in New Zealand waters. *G. piabilis* is tentatively used because this species is the most abundant of those present (Robertson & Mito, 1979).

Table 2.5 Meristic counts of Gymnoscopelus spp.

	First Dorsal	Anal	Pectoral	Pelvic	Gill Rakers
Moser *et al*. (1984)	14-21	16-22	12-16	8-9	6-12+14-26
This Study	18	19	13	8	5+15
Robertson & Mito (1979)	17	17	13	4(?)	?

Gymnoscopelus piabilis larvae fit into the 'moderately slender' morphotype mentioned in the discussion of *Diaphus* sp. Superficially, they resemble both tripterygiid larvae and *Diaphus* larvae that were also found in plankton samples

at the same time of year. Identification is made simple by the presence of a prominent photophore immediately anterior to the pelvic fin insertion (PO_5). Tripterygiid larvae possess no photophores, whilst *Diaphus* sp. larvae possess a prominent suborbital photophore (SO) which is absent in *G. piabilis* larvae. As with *Diaphus* sp. larvae, the anus is positioned at mid-body, and prominent melanophores exist along the dorsal-midline and ventral-midline of the caudal peduncle. In contrast, there is usually a large stellate melanophore above the brain (there may be more than one present in later stage specimens). This is absent in *Diaphus* sp., although there may be two small melanophores on the dorsal-midline behind the brain. Another possible difference is the relative eye diameter to head length ratio. *G. piabilis* appears to have a smaller eye relative to head length than *Diaphus* sp.

At 10.5 mm TL (Fig. 2.5 a) the caudal fin has well-ossified rays and is separated from both the dorsal finfold and anal finfold. The pelvic fins (and associated photophores) have not yet formed and the pigmentation above the brain is undeveloped. (Larvae at this stage can be distinguished from *Diaphus* sp. larvae of the same size by the absence of well-formed dorsal and anal fins and the absence of the suborbital photophore.) Large serial melanophores are prominent along the dorsal and ventral midlines of the caudal peduncle. A scattering of small melanophores can also be seen along the posterior margin of the caudal peduncle.

At 12.4 mm TL (Fig. 2.5 b) all the fins have appeared and the pigmentation above the brain is prominent. Fin rays in the first dorsal fin and anal fin are well ossified, but the pelvic fins have yet to develop to this stage.

A photophore (PO_5) immediately anterior to the pelvic fin insertion has appeared by 14.3 mm TL (Fig. 2.5 c). The apparent absence of the middle branchiostegal photophore (Br_2) may be an artefact of the opacity of the larvae, after preservation in alcohol.

Finally, by 22.2 mm TL (Fig. 2.5 d) the pigmentation along the dorsal midline of the caudal peduncle has extended forwards to above the anus, with paired melanophores either side of the dorsal midline. New melanophores have also appeared along the posterior portion of the lateral line. Counts of fin rays were made at this stage of development.

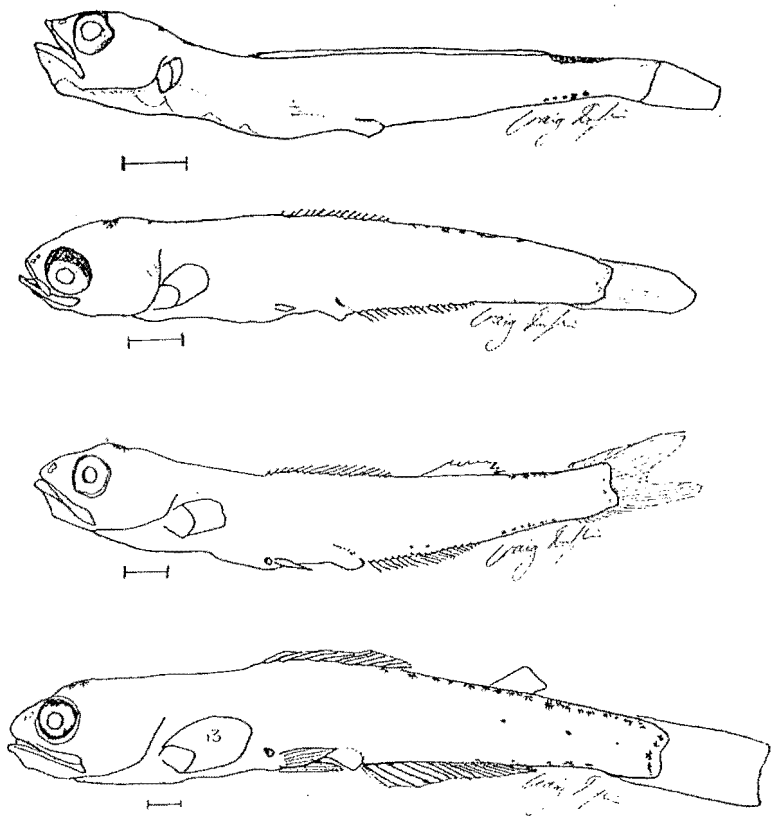

Figure 2.5 Development of *Gymnoscopelus piabilis*

(scale = 1 mm)

a) 10.5 mm TL

b) 12.4 mm TL

c) 14.3 mm TL

d) 22.2 mm TL

2.8 Order Gadiformes

Family Moridae

Pseudophycis bacchus (Bloch and Schneider) **Red Cod**

Red cod larvae and juveniles have never been described in the New Zealand literature. Crossland (1982) illustrated unknown morid larvae (4.2 mm & 7.5 mm TL) caught from October to February in the outer Hauraki Gulf and east of Northland. These were assigned the tentative identification of rock cod (*Lotella rhacinus*) on the basis that sexually mature red cod are not common in northern New Zealand (Crossland, 1982). However, since the adults of these species are morphologically very similar, it is unlikely that red cod larvae would differ greatly in appearance from rock cod larvae.

Eggs of red cod were described by Robertson (1975) as being spherical (0.775-0.900 mm Ø) with a non-segmented yolk, a smooth chorion, and a single oil droplet (Ø = 0.175 mm). He also suggested that red cod are spring spawners. This agrees with Habib (1975) who proposed a spawning season from October to November, and Graham (1956) who stated that red cod are spring spawners.

Red cod captured in this study (Ref. Collection CN) were all post-larval, but were still pelagic up until at least 55 mm TL. Most specimens were captured in daytime plankton tows at the surface of all four transect sites, during December and January, 1995/1996 and 1996/1997. Red cod juveniles were captured close to shore, as well as several kilometres offshore. By comparison, Crossland (1981) found no morid larvae in his close-inshore sampling stations.

Pelagic juveniles of this species are very distinctive compared to another common morid species found in this study, Ahuru (*Auchenoceros punctatus).* Ahuru have a distinctive separate first dorsal spine that is evident by c. 12 mm TL. Crossland (1982) stated that Ahuru could be distinguished from rock cod larvae, at smaller lengths, by having lighter pigmentation. Red cod would also probably be darker in pigmentation than Ahuru at small sizes, since the juveniles captured in this study were darker than their Ahuru counterparts. This requires verification.

Horn & Sullivan (1996) investigated ageing red cod with otoliths, and gave a range of estimated length-at-age results. The results for 0+ fish (equivalent to 7 months after hatching) were between 16 cm TL and 22cm TL. Specimens caught in this study (Fig. 2.6) and maintained in the aquarium grew to approximately 15 cm within a year. Given that aquarium conditions are seldom as good as those found in the wild, this is suggestive that red cod can grow as fast as suggested by Horn and Sullivan (1996).

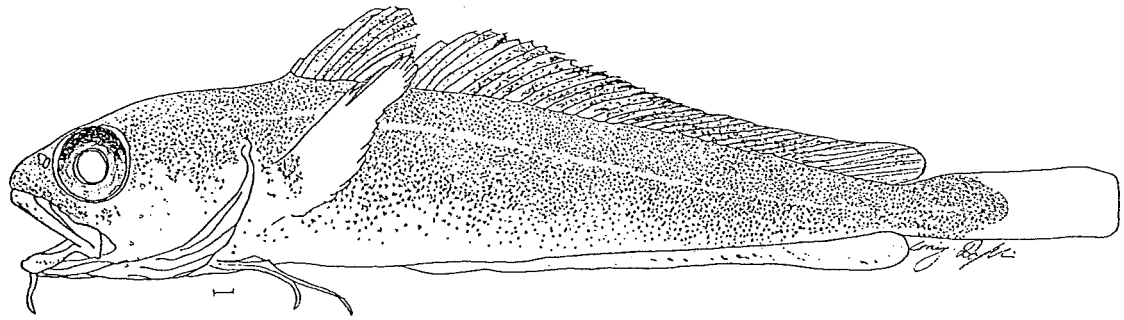

Figure 2.6 Red cod (*Pseudophycis bacchus*) pelagic juvenile (55.4 mm TL) (scale = 1 mm)

Order Gadiformes

Family Moridae

Auchenoceros punctatus (Hutton) **Ahuru**

Ahuru eggs were described and illustrated at a late stage of embryological development by Robertson (1975). They are smaller than red cod eggs with a diameter between 0.525 and 0.600 mm. Like red cod eggs they are spherical with a smooth chorion and a single oil droplet (0.150 mm Ø). Both Robertson (1980) and Crossland (1981) found that spawning occurs during the winter-spring season. Size at hatching is not known.

The larvae have been described in several works. Robertson (1973) illustrated a 24.8 mm TL Ahuru pre-juvenile. Crossland (1981) illustrated two specimens of 5.6 and 12.8 mm TL respectively. Lastly, Roper (1981) illustrates a 3.5 mm TL Ahuru larva. Kingsford & Barrington (1986) has constructed a developmental sequence with drawings reproduced from these three sources.

Specimens in this study were captured at the 4 km site in November 1996, during surface plankton tows. The smallest individual recognized was 10.5 mm TL and the largest was 40.5 mm TL. These were preserved in 95% ethanol (Ref. Collection AT) before being measured and drawn. Specimens were identified by comparison to illustrations in Kingsford & Barrington (1986).

Although size at hatching is not known, Roper's (1981) 3.5 mm individual is still absorbing its yolk-sac and is unlikely to be significantly larger than at hatching. Melanophores are scattered over the body in a random pattern that is generally denser on the ventral surface (Kingsford & Barrington, 1986). Some melanophores are present in a sparse grouping on the head. The abdomen is short, with the anus positioned at approximately one quarter of the body's length. The finfold is undifferentiated.

By 5.6 mm (Crossland, 1981) it appears that fin rays have begun to ossify within the still-continuous finfold. The gut seems to be more developed, and the anus has moved posteriorly to approximately one third of the body's length. Flexion has not occurred at this point.

At 10.5 mm TL (Fig. 2.7 a) the finfold has undergone differentiation. The anal and dorsal fins have become distinct from the caudal fin and the anterior

part of the dorsal fin has begun to constrict. Flexion has occurred at this stage. The newly caught specimens have a slightly pink-orange tinge to the otherwise opaque tissue. This fades to a milky white colour in alcohol. In Crossland's 12.8 mm TL specimen (1981, pg 22, fig. 15), the dorsal and anal fins are still continuous with the caudal fin. This could be an artifact of preservation method, with Crossland (1981) using 5% buffered formalin, and this study using 95% ethanol. Alcohol has a greater shrinkage effect (due to dehydration) than neutralized formalin. Alcohol preservation may have shrunk the specimens in this study to a length shorter than an equivalent larvae in Crossland's (1981) study. However, pelvic fins have appeared on Crossland's (1981) specimen prior to fin separation, whereas, in this study, the pelvic fins only arose after the caudal fin had begun to separate. This may indicate that there is variation in these stages of development, either between individuals, or between regions.

In alcohol preserved specimens, the pelvic fins (jugular) have appeared by 12.1 mm TL (Fig. 2.7 b) and the anterior ray of the dorsal fin has become completely separated from the rest of the dorsal fin. This is consistent with Crossland (1981). Initially this ray is a bud, but grows rapidly thereafter. Pigmentation on the head has become more dense and extends back to where the first dorsal ray is forming. There is also a distinctive series of melanophores along (below) the mandible. This can be seen in specimens from this study and also Crossland (1981). The main changes after this point in development are pigmentation patterns and fin shape.

By 24.8 mm TL (Robertson, 1973) the first dorsal ray has become elongated and is somewhat longer than the rest of the dorsal fin rays. Similarly, the two rays of the pelvic fins have become very elongate. Dorsally, pigmentation extends further back to behind the origin of the dorsal fin (excluding the prominent first dorsal fin spine). Ventrally, there is now heavy pigmentation from the anus backwards (reaching almost to the caudal peduncle). Head pigmentation is more dense, and extends forward to the snout. Some melanophores have also appeared in front of the pectoral fin insertion.

By 40.5 mm TL (Fig. 2.7 c) the dorsal pigmentation is continuous from the snout to the caudal peduncle and is spreading onto the flanks (also from the ventral pigmented area). At this point the first dorsal fin ray is approximately

three and a half times as long as the second dorsal fin ray, or about the same length as the head.

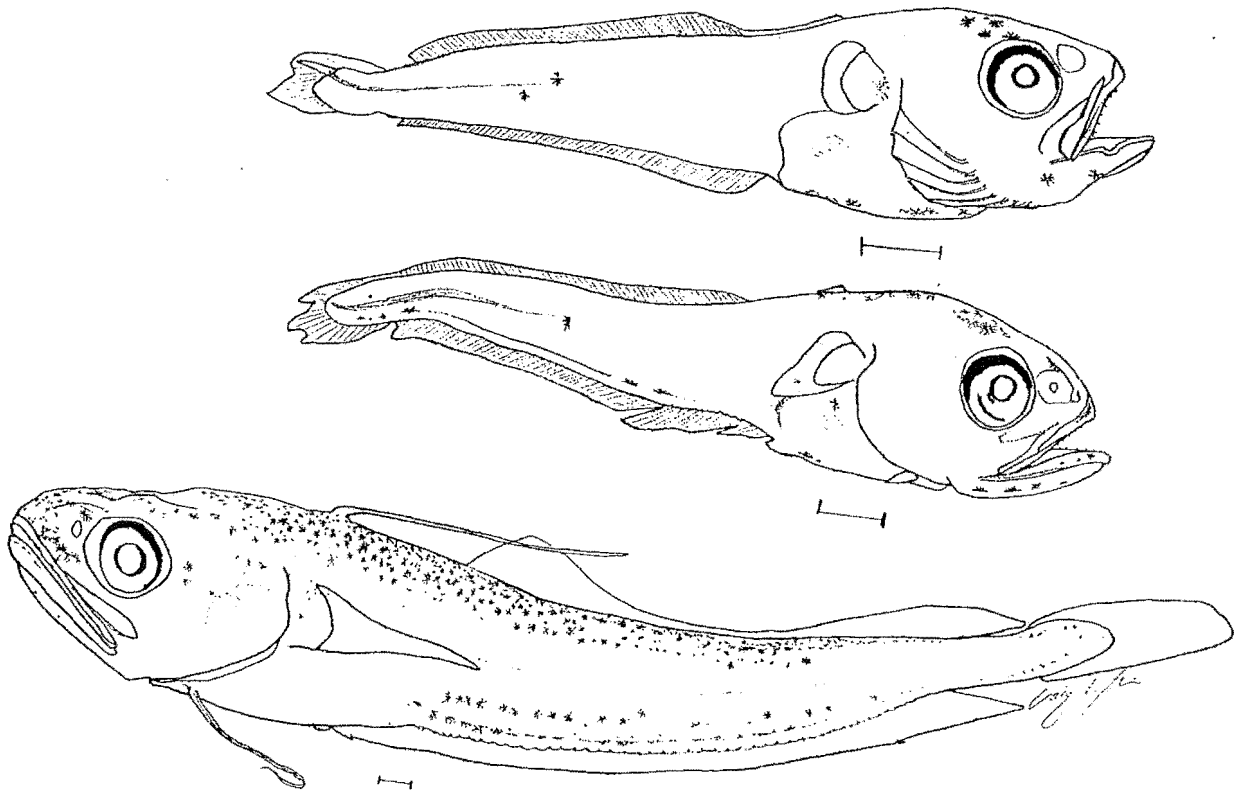

Figure 2.7 Partial Development of Ahuru (*Auchenoceros punctatus*)
(scale = 1 mm)
a) 10.5 mm TL
b) 12.1 mm TL
c) 40.5 mm TL

Order Gadiformes

Family Gadidae

Gaidropsarus novaezealandiae (Hector) **Rockling**

Rockling are one of only two 'true' cods known from New Zealand. Much work on gadids has been done worldwide (Dunn & Matarese, 1984). However, work on *Gaidropsarus* is more limited. Internationally, pre-juveniles and pelagic juveniles of *Gaidropsarus mediterraneus* and *G. bicayensis* have been illustrated (Demir, 1982). Work in New Zealand has been restricted to larvae and pre-juveniles of the rockling *G. novaezelandiae*. Robertson & Mito (1979) illustrated two larval rockling (9.5 mm TL and 24.6 mm TL). Larval and pre-juvenile rockling were the most abundant young fish on the Chatham Rise, from December 1977 to February 1978 (Robertson & Mito (1979).

Rockling in this study (Ref. Collection AX) were captured in surface plankton tows at the end of October and early November of 1996. No larvae smaller than 18 mm TL were captured, and the largest was 42.2 mm TL. Specimens were preserved in 95% ethanol.

Superficially, rockling resemble pre-juveniles of yellow-eyed mullet (*Aldrichetta forsteri*) with a densely pigmented body with metallic-silver flanks and a deep blue-green colour, above and below. This is a stark contrast to the brown colouration of settled specimens. Rockling pre-juveniles proved to be particularly hardy and could withstand the turbulence of capture within the plankton net successfully.

The style of swimming is markedly sinusoidal in captured specimens, and is highly distinctive compared to pre-juvenile yellow-eyed mullet. Smaller specimens swim with all fins extended, and their large pelvic fins spread out, probably to slow sinking. Periodically they cease swimming and sink to the bottom of the aquarium. When they are not swimming their body rests in a tight bend with the caudal peduncle nearly touching the head and the caudal fin itself bent away from the head.

The eggs, and size at hatching, of rockling are not presently known. The smallest specimen in the literature (Robertson, 1979) is 9.5 mm TL and is

heavily pigmented with very pronounced pelvic fins (c. 26% TL). The pelvic fins are heavily pigmented, primarily around the fin rays.

Also prominent are two spines on each side of the head. These are placed on the pre-operculum, midway between the eye and the pectoral fin insertion. The two spines share a common base and point posteriorly as well as out from the body. The upper spine is directed upwards also. There is no pigmentation on these spines at any stage of development. These spines are also present in larvae of other *Gaidropsarus* species (Demir, 1982) and may be a distinctive feature of this genus.

The caudal fin has not yet separated completely from the dorsal and anal fins, although the fins have become very constricted around the caudal peduncle and fin rays can be seen. The origin of the dorsal fin at this stage is at the same relative position as the origin of the adult fish's second dorsal fin. This doesn't change during development, so it is likely that the adult's first dorsal fin forms after the second dorsal fin.

By 18 mm TL (Fig. 2.8 a) the distal-half of the pelvic fins are heavily pigmented with melanophores. The rest of the fin is non-pigmented. The pelvic fins remain large in proportion to the animal's length (c. 26% TL).

The caudal fin has separated from both the second dorsal fin, and the anal fin. Body pigmentation has become even denser, and the caudal peduncle has a darkly pigmented patch. (This patch appears to be stress-related as it was observed to become imperceptible in acclimatised captive fishes until they were stressed by disturbance in the tank.)

The head spines have begun to reduce in size relative to the size of the head and have migrated closer to the eye than previously. The barbel on the chin has developed, as have the barbels found on the nostrils (although they are small at this stage). The first dorsal fin is not present, although there is a groove along the dorsal midline, anterior to the second dorsal fin, in which the first dorsal fin later appears.

At 24.6 mm TL (Robertson, 1979) the pelvic fins remain large although they have begun to decrease in proportion to the length of the animal (c. 21.5% TL). The pattern of dense melanophores on the pelvic fins remains, and the spines on the head have moved much closer to the eyes. Also, the first dorsal fin has appeared in the groove anterior to the second dorsal fin origin. This fin

is composed of many filamentous rays that are unconnected by membranes. The first ray is distinctly the longest of these.

The pelvic fin retains its distal pigmentation at 33.5 mm TL (Fig 2.8 b) but has become relatively shorter (c. 15% TL). Similarly, the spines on the head have become much reduced and it is mainly because of the surrounding non-pigmented area that enables them to be seen at all.

By 42.2 mm (Fig.2.8 c) the animal has begun to elongate noticeably (TL/BD ratio = 6.6, compared to 5.6 at 33.5 mm TL and 5.5 at 24.6 mm TL). The pelvic fins have lost their distinctive melanophore pattern, and have become reduced to approximately 13% TL.

Robertson (1979) commented that the National Museum's collection of rocklings, collected from rocky, sublittoral habitat of the east coast of the South Island, ranged from 40 mm TL to 138 mm TL. These represent settled individuals and it seems unlikely that rockling remain pelagic for long after reaching 40 mm TL. That individuals were capable of settling at this size was evident, with some assuming adult colouration and cryptic behaviour within two days of capture.

Behaviour typically consisted of burrowing under shells and rarely venturing out if disturbed. If not disturbed the animal would explore the aquarium freely, but would freeze or seek cover if disturbed. This persisted for many weeks, although by the end of this time they preferred to freeze when disturbed rather than seeking cover. Foraging behaviour when observed seemed to involve burrowing into the sandy substrate a short distance amidst a flurry of sand. Presumably they use their barbels to detect small invertebrate prey in the soft substrate. However, they also began to devour small fish-food pellets when encountered lying on top of the sand. Behaviour in a rocky substrate was not investigated.

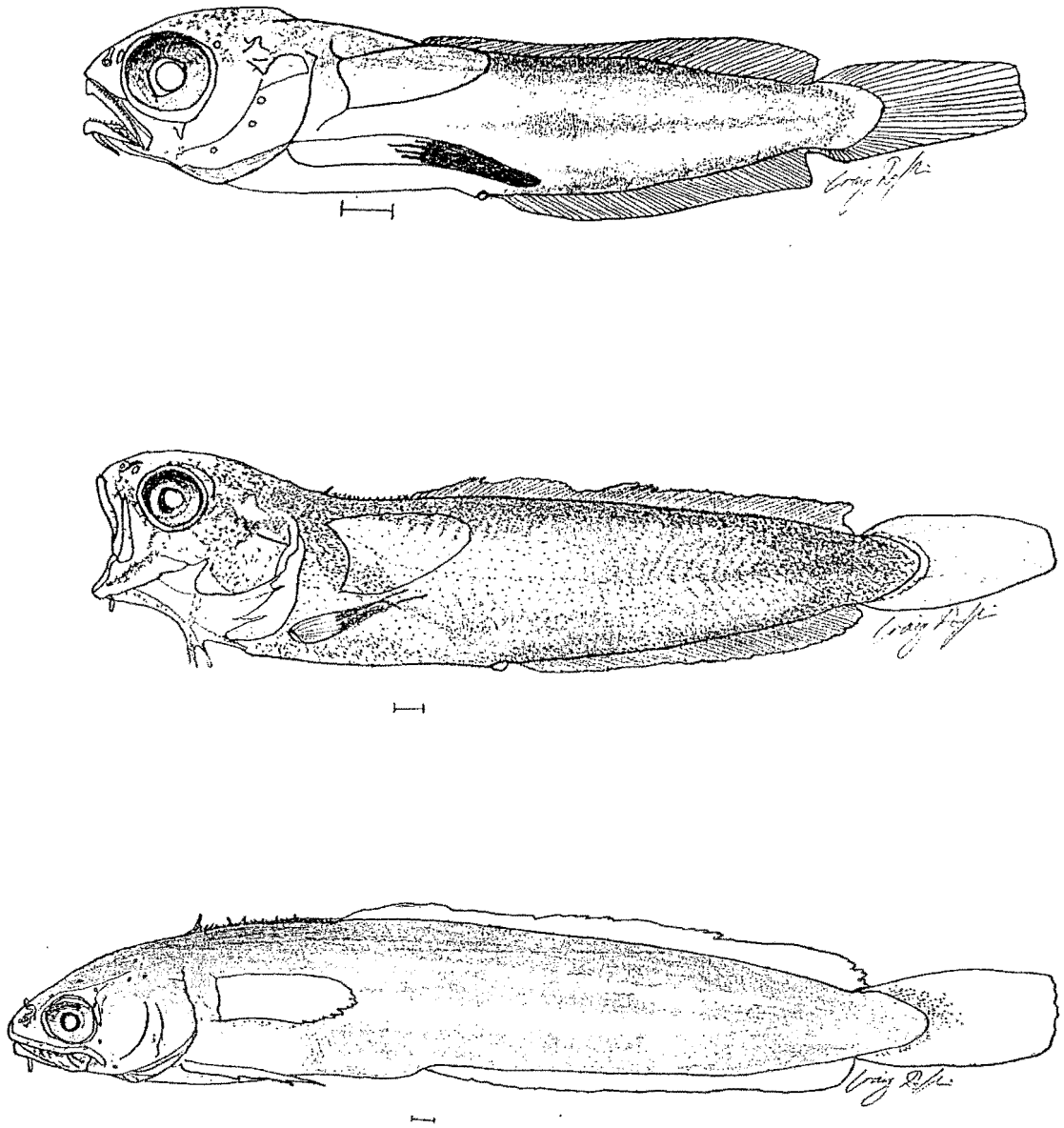

Figure 2.8 Partial Development of rockling (*Gaidropsarus novaezealandiae*)
(scale = 1 mm)
a) 18.0 mm TL
b) 33.5 mm TL
c) 42.2 mm TL

2.9 Order Ophidiiformes

Family Carapidae

The Carapid family is notable for the unusual associations that the majority of species form with various invertebrate hosts such as bivalves, asteroids, and holothurians. Some species dwell as inquilines inside the body cavities of their hosts (Markle & Olney, 1990).

The eggs and larval stages of most species are known from studies worldwide and, in particular, from studies in tropical areas where the family is most abundant and diverse (see references in Markle & Olney, 1990). Keys for both larval and adult identification can be found in Markle & Olney (1990).

The eggs of carapids are unusual in that they are usually ellipsoidal instead of spherical. Typically, they possess a single oil droplet and may be contained in a mucilaginous raft (Robertson, 1975).

Larvae are unique in having a vexillum at some stage of their larval development. The vexillum is a modified first dorsal fin element that is present during larval development (the vexillifer larvae) and is secondarily lost during metamorphosis into the tenuis juvenile stage. Thus, the first dorsal fin element of adult carapids is actually the second dorsal fin element of the larvae.

In New Zealand there are at least 7 species present. Of these, only *Echiodon pukaki* (Markle & Olney, 1990) and *Echiodon pegasus* (Markle & Olney, 1990) are undescribed as larvae. Markle & Olney (1990) suggest that larvae of *E. pukaki* are likely to be highly similar to the larvae of *Echiodon cryomargarites*.

Family Carapidae

Echiodon pegasus (Markle & Olney)

Echiodon pegasus was first described by Markle & Olney (1990) in their review of the systematics of the Carapid family, along with another new species *Echiodon pukaki*. Adult specimens have been found in several locations around southern New Zealand but most instances have been offshore from the east coast of the South Island. Larvae of this species have not been seen before.

Only one specimen was captured during this study. This was captured in a 3m deep plankton tow on November 3, 1995, in South Bay. The specimen was preserved in 95% ethanol prior to being drawn and measured. Identification was based on the fact that this specimen did not closely resemble any of the published illustrations of carapid larvae, including *E. cryomargarites* (thus probably eliminating *E. pukaki* (Markle & Olney, 1990)). Lastly, after being drawn, the specimen was sent to Dr. Douglas Markle (Dept. of Wildlife and Fisheries, Oregon State University, USA) for identification. He believes the specimen to be *E. pegasus* based on vertebral counts and other meristic measurements (pers. comm). The specimen is to be deposited at the Museum of New Zealand, Wellington.

The single specimen (Fig. 2.9) was dead upon removal from the net and was approximately 31 mm TL (2.97 mm HL). It possesses a long vexillum (~20%TL), which is a long straight spine with a small fleshy appendage at the tip. The distal tip of the fleshy appendage is tapered, and has a small black marking. Midway along the spinous portion of the vexillum is another pigmented area, which is present along c. 16% of the spine's length. The vexillum is attached vertically above the third anal fin ray.

The dorsal fin rays begin immediately behind the vexillum, and are initially less than 5% of the length of the vexillum. The rays gradually increase in length posteriorly and reach approximately 20% of the vexillum's length at about two thirds TL. Then they gradually reduce in length again, until disappearing at approximately 2 mm before the posterior tip of the body. There were c. 86 rays in the dorsal fin, and c. 92 anal fin rays, but these were not accurately counted before the specimen was sent to Dr. Markle. The anal fin origin is anterior to the dorsal fin origin (vexillum) and it terminates immediately opposite the termination of the dorsal fin. The abdomen of the larvae is very compact with the anus barely two head lengths back from the tip of the snout.

The eye diameter is approximately 22% of the head length. The mouth is terminal and the maxilla extends back past the posterior margin of the eye. The nasal rosette is non-pigmented but obvious. A small grouping of melanophores exists laterally behind the eye and extends to the posterior margin of the operculum.

Lastly, a distinctive pattern of melanophore spots can be seen on the sides of the animal. Eleven of these spots occur at regular intervals along the body. The first is a short distance behind the vexillum attachment and immediately above the lateral line. Others are generally centred on, or just above, the lateral line. These pigmented spots are prominent and can be seen even after a prolonged period in alcohol.

The function of the vexillum in carapid larvae is uncertain. In this instance the fleshy appendage at the tip of the vexillum bore a remarkable resemblance to copepods found in the same sample. The vexillum may, in this instance, be used similarly to the lure of angler fishes. Small larval fishes, or other predators of copepods, may become prey while investigating the lure. Other possible functions may include defensive armament.

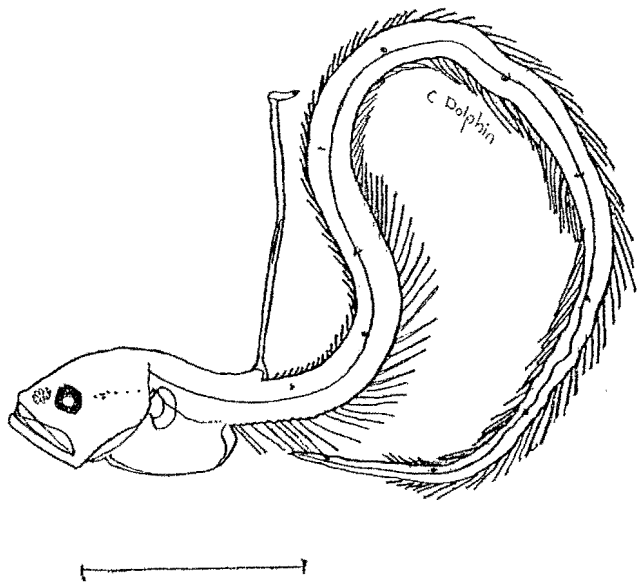

Figure 2.9 Vexillifer larvae of *Echiodon pegasus*
(scale = 5 mm)

Family Carapidae

Eurypleuron owasianum (Matsubara) **Pearlfish**

Eurypleuron owasianum has been extensively described in the international literature as both adults and larvae. Markle & Olney (1990) stated that there is little evidence for the existence of more than one species in this genus. They appear to be relatively widespread, with adults and larvae having been captured from the western Indian ocean to the eastern Pacific ocean.

Eggs have been fully described by Robertson (1975a) as being elliptical (long axis 1.15-1.20 mm, short axis 1.000-1.075 mm) with a segmented yolk.

Larvae are characterised by large lateral pigment blotches in younger larvae, and a looped, trailing gut in larger larvae (Markle & Olney, 1990). In New Zealand, Robertson (1973, 1975b) described and illustrated three larvae, attributed to *Echiodon rendahli.* These larvae were later reassigned to *Eurypleuron owasianum* by Markle & Olney (1990).

Only two larvae were captured in this study. Both of these were caught as eggs and incubated in captivity. These were caught in a plankton tow on December 20, 1996, at the 2 km site at a depth of 1m. They were among a rich catch of many fish eggs. The larvae hatched on December 21 and still possessed a large yolk-sac (Fig. 2.10 a). Size at hatching was 4.05 mm TL (n=1). The yolk-sac larvae have four distinctive lateral patches of pigment. The most anterior of these is positioned above the anus at the ventral midline of the body. The remaining three are evenly spaced along the remainder of the body. One larva died during measurement at this point. This was preserved in 95% ethanol (Ref. Collection BQ).

The vexillum first appeared two days after hatching. At this stage the larva measured 6.25 mm TL (n=1). This is less than Robertson's (1975b) 2 day-old mean length for 7 larvae (6.55 mm TL). The dorsal view was drawn using a cameralucida. No attempt was made to draw the lateral view of the sole survivor accurately, although a rough lateral sketch was made (Fig. 2.10 b). At this stage the vexillum appears as a small protrusion in the dorsal finfold anterior to the anus. The lateral melanophores have expanded and fine orange chromatophores are present at the same locations as the melanophores. Also,

a patch of white pigment can be seen extending from the tip of the caudal peduncle (posterior to the last melanophore patch) onto the caudal finfold.

The yolk had been completely absorbed by one week after hatching (6.93 mm TL). Again, no attempt was made to accurately draw the larva for fear of damaging it. A sketch was made (Fig. 2.10 c) which shows the approximate dimensions of the vexillum.

The fin rays nearest the posterior tip of the finfold are beginning to ossify distally at this stage. The most posterior melanophore has spread onto the finfold, both above and below the body. The large white chromatophore has reduced into three pairs of small white chromatophores around the tip of the caudal peduncle (three dorsally, three ventrally). The vexillum is enlarged (vexillum length=0.6 mm) at this point. Some orange colouration is still present but mainly obscured by the still-expanding lateral chromatophores.

The last larva died on December 30. It is assumed that the larva did not commence feeding on the rotifers and brine shrimp nauplii available to it. Unfortunately, the larva was not retrieved in time to prevent its consumption by scavenging protozoans.

Both Robertson (1975b) and Markle & Olney (1990) describe the later stages of development from a series of individuals captured in plankton tows.

From their illustrations it can be seen that the distinctive trailing, looped gut of later stage larvae is evident by c. 10.5 mm TL. At this point the distinctive melanophore pattern can still be seen clearly (Robertson, 1975b), and fin rays are evident.

The melanophore patches are reduced, and the pattern is much less distinctive, by 22 mm TL. The protruding gut has, conversely, become more evident (Markle & Olney, 1990).

The melanophore pattern has completely vanished, and the trailing gut is very prominent at 92 mm TL (Markle & Olney, 1990).

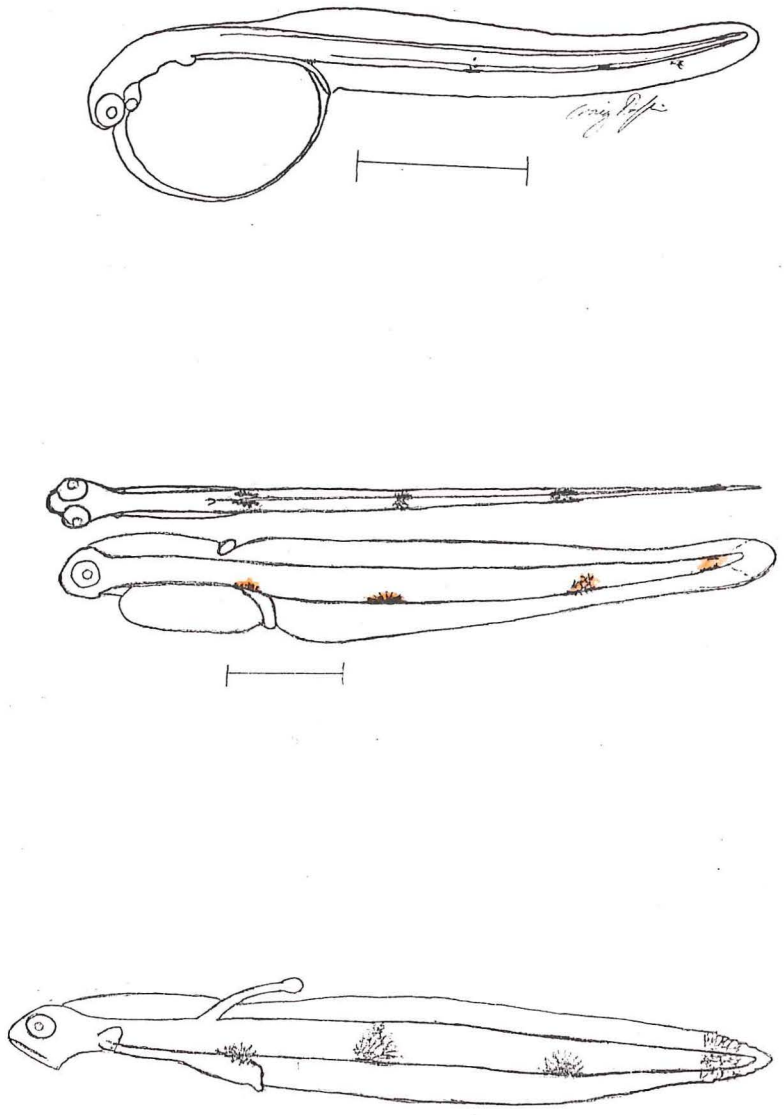

Figure 2.10 Early development of *Eurypleuron owasianum* larvae

(scale=1 mm)

a) 4.05 mm TL

b) 6.25 mm TL (Lateral is sketch only)

c) 6.93 mm TL (Sketch only)

2.10 Order Gobiesociformes

Family Gobiesocidae (Clingfishes)

Clingfishes are benthic predators of small invertebrates in the intertidal and sublittoral down to 100m. Eggs are laid demersally under rocks and egg-masses are usually attended by an adult until hatching. Eggs and larvae of clingfishes have been described in detail. Particularly good drawings of 5 species (*Diplocrepis puniceus*, *Trachelochismus pinnulatus*, *Trachelochismus melobesia*, *Gastroscyphus hectori*, and *Gastroscyathus gracilis*) can be found in Ruck (1976). Elder (1966) contains illustrations of three species (*Dellichthys morelandi, T. pinnulatus*, and *T. melobesia*), while Frentzos (1980) contains photographs of *T. pinnulatus*, *T. melobesia*, *D. puniceus*, *G. hectoris*, and *D. morelandi*. Published illustrations and descriptions of embryological development and yolk-sac larvae can be found in Ruck (1973a) for *Diplocrepis puniceus* and *Trachelochismus pinnulatus*, and in Ruck (1971) for *Trachelochismus melobesia*. Kingsford & Barrington (1986) also has illustrations of these three species (two redrawn from Ruck 1973a). Seven species of clingfish have been recorded in Kaikoura (Edward Percival Field Station teleost species record) but only one was recognised from larvae in this study.

Family Gobiesocidae

Trachelochismus melobesia (Phillipps) **Painted Clingfish**

The painted (or barred) clingfish is an endemic species and is common around New Zealand. Accounts of its early life history are found in Roper (1981, redrawn in Kingsford & Barrington, 1986), Elder (1966), Frentzos (1980), Thomson (1983), and a full description is found in Ruck (1971).

In this study, specimens were caught in spring and early summer (September - December) in 1995 and 1996. At times they were highly abundant and were particularly abundant in tows taken from immediately adjacent to reefs. Many larvae were still alive upon removal from the net and some were able to be reared successfully in captivity. Most, however, died within two days

of capture suggesting that net damage, or capture-associated trauma, was a problem. Larvae had green pigment on the body *in vivo*. Dead larvae were preserved in 95% alcohol before being measured and drawn (Ref. Collection X).

The smallest specimen captured was 5 mm TL. This is smaller than measurements recorded for yolk-sac larvae by Ruck (1971) and is probably an artefact of alcohol preservation and rigor mortis. Ruck did not record if his measurements were those of larvae that were alive, dead, or preserved.

Ruck (1971) described mean length at hatching to be 5.7 mm TL. Roper's (1981) description of yolk-sac larvae mentions a distinctive alternating pattern of melanophores on the ventral contour of the gut. Specimens in this study did not have melanophores along the ventral contour, and are consistent with Ruck's (1971) description which did not mention these melanophores. Ruck (1971) described the upper peritoneum of the gut as being covered with numerous stellate melanophores. Also, stellate melanophores were observed in the myomeres just behind the vent.

The yolk-sac is almost completely absorbed at 6.5 mm SL (total length unknown) and the jaws are well formed and functional. At this point the sucker buds (modified pelvic fins) have appeared ventrally to the gills and heart. From Ruck's (1971, pg. 8, Fig.3) illustrations it can be seen that caudal fin rays begin to ossify before dorsal and anal fins.

At 7.2 mm TL (Fig.2.11 b) the suckers have developed more fully and the dorsal, anal, and caudal fins all have rays forming although they have yet to separate from each other. Pigmentation at this stage has not changed greatly.

Ruck (1971) reported that the larvae were able to use their suckers to adhere to the sides of glass jars by the time they reached 7.85 mm SL (total length not available). He also described a coincidental flattening and broadening of the head, and an increase in the depth of the tail at this stage. Similar observations were made during this work. Ruck (1971) suggested that the absence of planktonic larvae longer than 7.85 mm SL, and the apparent functionality of the sucker, indicated that larvae settled out of the plankton and attached themselves under rocks at this stage. In this study, the smallest individual to metamorphose was 9.5 mm TL. Two others also underwent metamorphosis but were slightly larger (c. 10 mm). The smallest settled

specimen captured while searching for egg masses in the intertidal was 12 mm TL.

At metamorphosis the juvenile clingfishes were an orange-brown colour, with a prominent pink-white dorsal saddle extending from just behind the eyes to the origin of the dorsal fin. The head was a dark brown colour with two transverse blue stripes running across the cranium and snout, between the eyes (Fig.2.11 c).

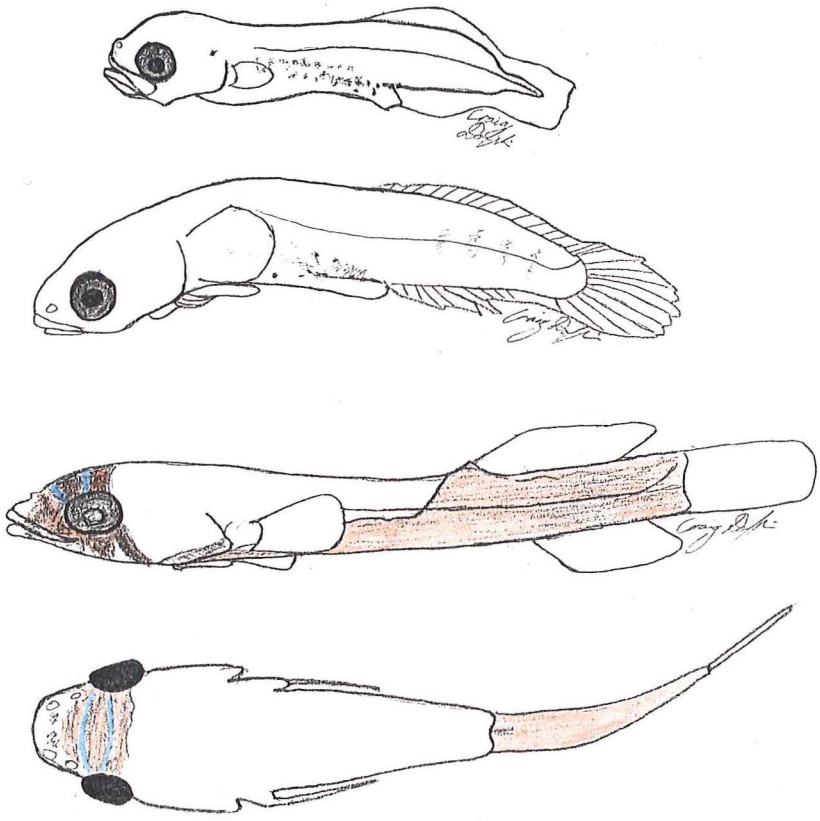

Figure 2.11 Development of *Trachelochismus melobesia*

a) 5 mm TL

b) 7.2 mm TL

c) 9.5 mm TL

2.11 Order Beryciformes

Family Trachichthyidae (Roughies, Slimeheads)

Paratrachichthys trailli (Hutton) **Common Roughy**

The eggs of the common roughy (or sandpaper fish) have been described by Robertson (1975) as having a diameter from 1.775 - 1.900 mm, no oil droplets, and a segmented yolk (which loses its segmentation at blastopore closure).

The only larval-stage roughy in the New Zealand literature is the slender roughy, *Optivus elongatus*, which Crossland (1981) briefly described and illustrated (5.3 mm TL). His illustration was reproduced in Keene & Tighe (1984), and also Kingsford & Barrington (1986) under the name *Hyplosthethus elongatus*.

Eggs identified as *P. trailli* in this study had a diameter between 1.73 and 1.93 mm (mean = 1.86 mm; sd = 0.06; n = 12), no oil droplet, and a segmented yolk which persisted throughout development (Fig. 2.12 a-c). This last contrasts with Robertson's (1975) description, and this identification should be treated as tentative. Also, although there was pigmentation present on late stage embryos the pigmentation was much lighter than that shown in Robertson's (1975) illustration. Like Robertson's (1975) description this pigmentation does not extend onto the caudal peduncle. The yolk was spotted by regularly placed melanophores, which can be seen in Robertson's (1975) illustration. Furthermore, the timing of egg capture (January and February 1997) agrees with Robertson's (1975) observation that *P. trailli* eggs occur in Kaikoura during summer and autumn.

In the earliest stage egg captured (Fig. 2.12 a), the blastodisc covers less than 40% of the yolk. Segmentation within the yolk is not obvious, but may have been missed by the author. Within a day, the blastodisc covers the yolk and the long axis of the embryo is clearly visible. The yolk is segmented, with small melanophores scattered in a regular pattern across it.

The embryo has developed more by the second day (Fig. 2.12 b) with the trunk of the body notching deeply into the yolk by this stage. The caudal peduncle is free of the yolk. Yolk segmentation is more prominent, as are the

regularly spaced melanophores across the yolk. The otic capsule is barely visible, and body pigmentation is light green-brown.

Prior to hatching on the third day after capture (Fig. 2.12 c), the pectoral fin buds could be seen just above the yolk with the tail wrapping around the yolk and just reaching the head.

Upon hatching, the yolk-sac larvae (Fig.2.12 d) are a mean length of 4.24 mm TL (n = 3, sd = 0.15). Pigmentation on the body reduces after hatching, and the larvae spend most of their time motionless within a few millimetres of the surface.

By the next day (Fig.2.12 e) the larvae are beginning to develop dark pigmentation dorsally and laterally. Melanophores are sparsely distributed across the upper peritoneum of the gut. A small remnant of the yolk sac has yet to be absorbed. Segmentation in the posterior part of the yolk is no longer visible. The eyes are still non-pigmented at this stage.

Three days later (Fig.2.12 f) the larvae have completed yolk-sac absorption and are approximately 5.58 mm TL (n = 1). The eyes have become darkly pigmented, and body pigmentation is darker and more developed but does not extend onto the caudal peduncle. The melanophores on the upper peritoneum of the gut are more extensive and obvious. Also, extensive pigmentation can be seen along the ventral contour of the body. No pigmentation is visible on the finfold.

The gut is well formed and the anus is positioned at just behind mid-body The pectoral fins are larger and more obvious, and pelvic fins have appeared at mid-gut. These are inserted latero-ventrally, and are very small at this stage.

Larvae did not appear to be feeding and were positioned mostly near the bottom of the aquarium, hovering at an angle approximately 30 degrees from horizontal with the anterior end downwards. One or two did not stay at the bottom of the tank and appeared to be more active. These individuals proved to be the longest living of the larvae by at least 3 days.

On the 8h day after hatching (Fig.2.12 g) the larvae were 5.22 mm TL. The reduction in length is attributed to metabolic requirements for developing structures, such as pelvic fins, together with apparent starvation. The larvae had rotifers and brine shrimp nauplii available to them but did not seem to be successful at capturing them. Several instances of larvae snapping at food

items were noted, but the food was either an inappropriate size, or unpalatable. Alternatively, the larvae were not very efficient predators in the conditions (e.g., light intensity) present in the laboratory. Only three larvae of the original 13 remained alive at this point.

At this stage the pigmentation is darker and distributed more evenly across the head and body (anterior to the caudal peduncle). There is some pigmentation extending into the subdermal space of the dorsal finfold at approximately mid-body, and the ventral finfold behind the anus. This may be suggestive of developing muscle blocks for future dorsal and anal fins.

The anterior part of the dorsal finfold has begun to reduce in height. The pelvic fins are larger, and it is possible to see some pelvic fin rays.

The last two larvae died on the eleventh day after hatching (Fig.2.12 h) and were 4.66 mm TL. Obviously the larvae were starving to death, and it is probable that autolysis had begun.

At this stage the pelvic fins are enlarged and darkly pigmented. The anterior part of the dorsal finfold is very reduced and fin rays are just beginning to form above and below the caudal peduncle. Small muscle blocks can be seen at the bases of the anal fin rays, although the fin rays themselves are not yet visible. The dorsal fin is visible only by the shape of the finfold. The head is larger in proportion to the length of the body, but this may be an artefact of starvation rather than a true developmental feature. At this point, the caudal peduncle is still non-pigmented.

From comparison to Crossland's (1981) illustration of the slender roughy larva, it can be seen that common roughy larvae are more elongate and less developed at the same length as the slender roughy. It is possible, however, that the poor nutrition of these larvae may have contributed to this situation.

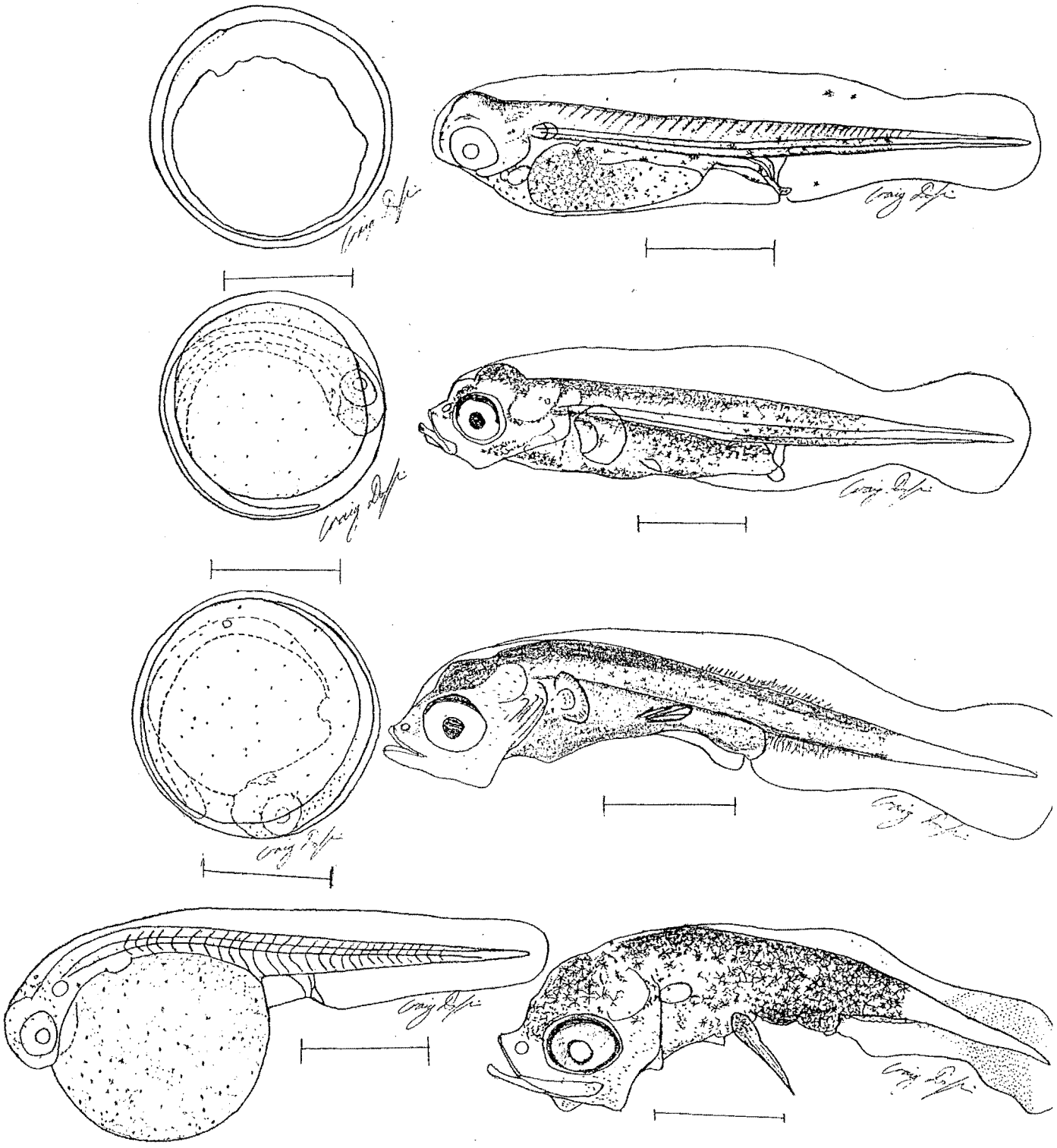

Figure 2.12 Development of eggs and early larvae of *Paratrachichthys trailli* (scale = 1 mm)

Eggs (hours after capture):

a) 3.75h

b) 33.25h

c) 50.5h

d) yolk-sac larvae

Larvae (days after hatching):

e) 1 day old

f) 4 days old

g) 8 days old

h) 11 days old

2.12 Order Syngnathiformes

Family Syngnathidae

Leptonotus elevatus (Hutton) **Pipefish**

Pipefishes are unusual in that they exhibit mate choice by males (Ahnesjo, 1995) and male brooding of eggs and embryos. This latter is a feature of the family (Syngnathidae). Some species of pipefish do not have a specialised brood pouch (usually located on the tail in pipefishes) and females may simply glue their eggs to the trunk of the male (Vincent *et al.*, 1995). In those species with a brood pouch, there is evidence of competition for resources within the pouch by the embryos (Ahnesjo, 1996). Nothing has been recorded about reproductive strategies for *Leptonotus elevatus* in New Zealand. Pre-juvenile pipefishes have been found from around New Zealand in most coastal plankton studies (e.g., Crossland, 1981; Elder, 1966; Kingsford & Barrington, 1986).

Short-snouted pipefishes (*Lissocampus filum*) as small as 6.4 mm TL have been illustrated (Roper, 1981, reproduced in Kingsford & Barrington, 1986). At this small size, the anal fin can be clearly seen behind the anus and the caudal fin is present. Also, the dorsal fin base is relatively short. Frentzos (1980) contains a photograph of a 7.3 mm TL specimen, and Elder (1966) illustrated an 8.5 mm TL specimen of *L. filum.*

In the long-snouted/smooth pipefish (*Stigmalophora macropterygia*) the caudal and anal fins are absent (Roper, 1981; Kingsford & Barrington, 1986; Elder, 1966 (syn. *S. longirostris*)).

However, there are 5 pipefish species present in New Zealand (Paulin *et al.*, 1989), of which only the two species above have been illustrated as larvae or pre-juveniles. If development of structures used in adult identification is not complete at emergence then there is potential for misidentification of these larvae. Elder (1966) stated that the relative proportions of head parts from *S. macropterygia* remain constant during development, although other measurements (e.g., head length) may change with increasing total length. This is probably similar to *L. elevatus.*

At 32.88 mm TL (Fig. 2.13) the pipefish (*Leptonotus elevatus*) is identifiable using adult characteristics, and counts of dorsal and caudal fin rays are

possible. The anal and pelvic fins are absent, and the snout is 40% HL. The presence of a caudal fin should be sufficient to distinguish this species from long-snouted pipefish of similar size. The length of the snout may be sufficient to separate this species from the short-snouted pipefish, but the absence of an anal fin is a more reliable character. Characters useful for identifying larval syngnathids are presented in Table 2.6. Unfortunately, no specimens of this species were collected that were small enough to compare directly to the specimens illustrated in Elder (1966) and Kingsford & Barrington (1986).

A similar individual of 21.2 mm TL was photographed in Frentzos (1980) and identified as *Leptonotus blainvillianus*. It is likely that Frentzos' (1980) specimen is *L. elevatus*, using current nomenclature.

Table 2.6 Larval meristics of four syngnathid species from New Zealand.

	Snout/HL	Dorsal	Anal	Caudal
Leptonotus elevatus	c. 40%	38	none	10
*Lissocampus filum**	c. 35-40%	<20	present	9
*Stigmalophora macropterygia**	c. 55%	30	none	none
Hippocampus abdominalis	c. 45%	29	present	none

* from Elder, 1966

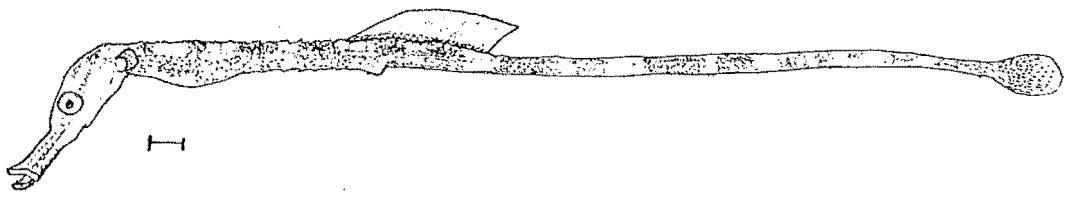

Figure 2.13 Juvenile pipefish (*Leptonotus elevatus*) 32.88 mm TL (scale = 1 mm)

Order Syngnathiformes

Family Syngnathidae

Hippocampus abdominalis (Lesson) **Seahorse**

Seahorses are closely related to pipefishes and, like pipefishes, exhibit male brooding of eggs and larvae. However, unlike pipefishes, seahorses do not exhibit male mate choice (Vincent, 1994). Eggs are fertilised externally and are then placed in the male's abdominal brood pouch. Within the pouch they undergo embryological and larval development, before emerging as competent juveniles. Recent work in Australia has shown that seahorses (*Hippocampus whitei*) are remarkable because they are truly monogamous. They form pair bonds which last for the life of the animals (Vincent & Sadler, 1995). This is the only verified account of teleostean sexual fidelity.

Seahorses are morphologically similar to pipefishes but differ in that the head is bent forwards at the neck, and the tail (without a caudal fin) is prehensile and usually coiled at the posterior end. Characteristics useful in separating syngnathids are presented in Table 2.6.

Graham (1939, 1956) described transfer of eggs from female to male, and the release of larvae (17 mm TL), from a brooding male captured in Port Chalmers during January. Elder (1966) captured three larval seahorses during plankton tows in Wellington Harbour. One was caught in January, and two in February 1963. Crossland (1981) noted that larval seahorses were occasionally captured during plankton tows in the Hauraki Gulf between October and January 1974/75 and 1975/76. He did not state if these appeared throughout the sampling period or if they appeared only towards the end of it. Seahorse pre-juveniles were captured in Kaikoura throughout the year.

Elder (1966) gives a full description of seahorse larvae and illustrated a 16 mm TL specimen. Specimens collected in this study (Ref. Collection CO) do not deviate from Elder's (1966) description (Table 2.6; Fig.2.14).

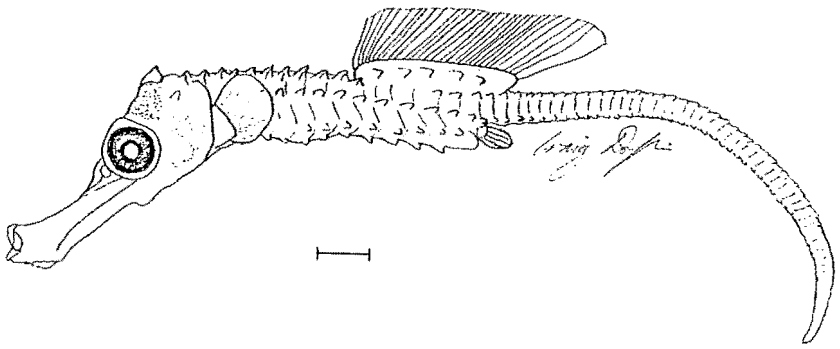

Figure 2.14 Juvenile seahorse (*Hippocampus abdominalis*) 20 mm TL

2.13 Order Scorpaeniformes

Family Scorpaenidae

Scorpaenid larvae have been described from the Hauraki Gulf (Crossland, 1982), Wellington harbour (Elder, 1966), and the Otago coast (Robertson, 1973; Graham, 1956). Crossland (1982) quotes descriptions from Graham (1956) of larval *Helicolenus percoides*, and larval *Scorpaena* spp. from Moser *et al.* (1977), and tentatively identifies unknown 3.6 mm (notochord length) scorpaenid larvae as *H. percoides* based on these descriptions. Elder (1966) considered that these two scorpaenid larvae were inseparable below a length of c. 8 mm TL, and were only identifiable at this length on the basis of body depth/length ratios and soft-dorsal fin ray counts. However, it must be noted that both Elder (1966) and Crossland (1982) used formalin preserved specimens. The effects of preservation on body depth/length ratios have not been established for these species. Personal observation suggests that these ratios are likely to be higher in preserved specimens than in non-preserved specimens (due to shrinkage). Potentially, long term preservation may cause differences between newly preserved specimens and those preserved for a long time. This is more likely to be true in very small larvae where little ossification of skeletal structures has yet occurred.

Graham (1956) described *H. percoides* to be viviparous, and extrude young over an extended period (September - May). This was verified by Elder (1966) who extended this period to include the latter half of August.

In this study, small scorpaenid larvae (Fig.2.15 a, b) were captured, from February to March, during both summers (1995/96 and 1996/97) of the study (Ref. Coll. Y). Scorpaenid larvae were also occasionally captured during October, December, and January of 1996/1997. These were usually at a depth of 1m or 3m below the surface (although a few were infrequently captured near the surface). They were mostly captured at inshore sites, such as South Bay or near the mouth of the Kowhai River, rather than at offshore sites. The smallest of these larvae were c. 2.5 mm TLL, and the largest larva captured was 5.5 mm TLL.

Scorpaenid larvae are relatively hardy, and many survived capture in the plankton net used in this work. Several unsuccessful attempts were made to

rear these larvae but they did not begin feeding on brine shrimp nauplii or rotifers. Wild caught copepods were also used, but the larvae did not feed on these prey items either. It is probable that these larvae can be reared successfully, since they are relatively easy to capture alive and in viable condition.

These larvae have a highly characteristic melanophore patch (Fig. 2.15 a) on the ventral midline of the body. This is immediately posterior to the midpoint between the anus and the end of the notochord. Additionally there are stellate melanophores immediately anterior to the anus on the dorsal surface of the gut peritoneum and on the ventral surface of the gut. These are relatively small in very small specimens (<4 mm), but expand and spread anteriorly across the gut, dorsally past the pectoral fin insertion, and onto the head as larvae develop.

By 5 mm TLL a small melanophore patch can be seen at the front of the lower jaw and several spines have developed on the operculum and head (Fig. 2.15 b). Spines present are parietal, pterotic, and second posterior preopercular. At this length, the caudal fin rays have begun to ossify and the anterior of the dorsal finfold is reduced in height. This is essentially unchanged at 5.5 mm TLL, although more spines have appeared (supraocular, first anterior preopercular, and fourth and fifth posterior preopercular (Fig. 2.15 c)).

There are many species of scorpaenid present as adults in Kaikoura. The most common of these are the seaperch (*H. percoides*), the bigeye seaperch (*H. barathri*), and the red scorpionfish (*Scorpaena papillosus*). If Crossland's (1982) suggestion that the style of mid-ventral melanophore pattern is a potential indicator of genus, is followed, then this species is most likely to be *Helicolenus* sp.

The presence of a distinctive melanophore patch on the lower jaw (which is not apparent in illustrations of *H. percoides*) and the presence of later stage larvae of *H. barathri*, suggest that these may be early larvae of *H. barathri*. Also, some eggs captured in late January 1997 were hatched out in the laboratory. Two of these were identified as the same as the wild-captured scorpaenid larvae and, since these were collected as eggs, this species is unlikely to be the viviparous *H. percoides*.

Differences between adults of the two *Helicolenus* species are minor, and the main difference, eye diameter to head length ratio, is variable during larval development. It is unlikely, therefore, that these two species will be separable as larvae unless there is some species-specific character evident in the larval phase. It is suggested here that the melanophore patch on the lower jaw symphysis of early-stage larvae may be one such character. However, further investigation is required to validate the tentative identification made in this section, and also that this character is absent from *H. percoides* as seems to be the case from illustrations in Elder (1966) and Crossland (1982). An alternative explanation is that the absence of the melanophore patch may be an artefact of pigment loss after preservation in formalin.

A similar melanophore patch to that observed in these larvae can also be seen in larvae of *Helicolenus dactylopterus* (North Atlantic) and some species of *Sebastes* from the eastern Pacific (Moser *et al.*, 1977). This patch appears to be restricted to members of the subfamily Sebastinae (*Helicolenus* and *Sebastes*) and does not appear in illustrations of other scorpaenid subfamilies in Moser *et al.* (1977). This supports the assignation of this species to the genus *Helicolenus* rather than *Scorpaena*.

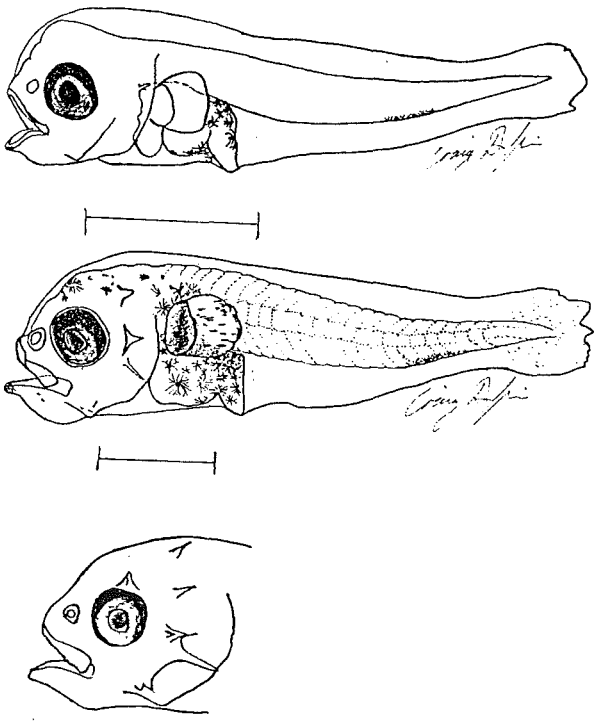

Figure 2.15 Unidentified scorpaenid larvae (probably *Helicolenus barathri*)

(scale = 1 mm)

a) 3.4 mm TL

b) 5.0 mm TL

c) 5.5 mm TL (Sketch only)

Family Scorpaenidae

Helicolenus barathri (Hector) **Bigeye Seaperch**

Larvae of *Helicolenus barathri* have not previously been identified. A potential candidate for early larvae of this species is described and illustrated in the previous section.

Later stage larvae of *Helicolenus barathri* were collected in plankton tows during April 1996 (Ref. Coll. AG). These were captured immediately below the surface in daytime tows and were further offshore than the early stage scorpaenid larvae. Most individuals were captured at the 2 km site.

Most of these larvae were alive upon removal from the net and one was reared from a size of approximately 16 mm TL to a length of 28.8 mm TL. Others died after a short period in captivity. The cause of mortality is unknown. Food during rearing consisted of fortified brine shrimp nauplii and adults and supplemental feeding of mosquito larvae. The smallest of these larvae were c. 8 mm TL. No larvae intermediate in size between the largest suspected early-stage *H. barathri* and the smallest confirmed *H. barathri* were captured.

These larvae are highly distinctive upon removal from the net because they have a prominently silver gut peritoneum, with the rest of the body being translucent. The eyes are darkly pigmented, and there are some yellow/orange pigment spots on top of the head, above the eyes.

At 8.7 mm TL the larvae have well-formed head armature, and pigmentation on the cranium is present but not obvious. The densely pigmented gut peritoneum is metallic silver in appearance. This silver colour is lost after a long period of preservation in formalin. The pelvic fin has begun to develop below the pectoral fin insertion, although fin rays are not yet evident. Dorsal and anal fin rays are weakly ossified and were not counted.

The spines on the head are large and obvious. Spines present, using Moser & Ahlstrom's (1978) terminology, are supraocular, parietal, nuchal, pterotic, first, second, third and fifth posterior preopercular, supracleithral. A full account of spines present at different lengths is presented in Table 2.7.

At 14.6 mm TL (Fig. 2.16 b) the main changes are a reduction in the relative size of the head spines accompanied by an increase in cranial

pigmentation. Dorsal and anal fins are more developed with fin spines and rays visible. The pelvic fins have also developed more completely. Meristic counts are given in Table 2.8.

At 16 mm (Fig 2.16 c) there are small melanophores present on the operculum and cranial pigmentation is increasing still. The relative size of the head spines is still decreasing. In particular, the spine above the orbit (supraocular) and the supracleithral spine, have almost disappeared. However, two new spines have appeared on the upper operculum (upper opercular & lower opercular spines). Meristic counts are given in Table 2.8.

Colouration of larvae kept in captivity did not change significantly (Fig. 2.16 d) until a size of approximately 25 mm TL was reached. This may suggest that this species settles at a larger size than *Scorpaena papillosus* (which readily adopts adult colouration at 20 mm TL).

Table 2.7 Appearance of spines on *H. barathri.*

Total Length	SPO	PA,NU,PT	APO	PPO	UOP,LOP	SC	UIO-1
3 mm*	-	-	-	2nd	-	-	-
5 mm*	-	PA,PT	-	2nd	-	-	-
5.5 mm*	present	PA,NU,PT	-	2,3 & 4	-	-	?
8.4 mm	present	PA,NU,PT	2 & 4	2,3 & 4	-	SC	present
12.0 mm	present	PA,NU,PT	2 & 4	1 - 5	-	SC	present
15.5 mm	reduced	PA,NU,PT	2 & 3	1 - 5	UOP,LOP	SC	-
22.5 mm	-	PA,NU	-	1 - 5	UOP,LOP	SC	-

*identification tentative

Table 2.8 Meristic counts for *Helicolenus barathri* at two lengths.

Total length	Dorsal	Anal	Pelvic	Caudal
14.6 mm	X,10	III,5	I,5	31
16.0 mm	XII,12	III,5	I,5	-

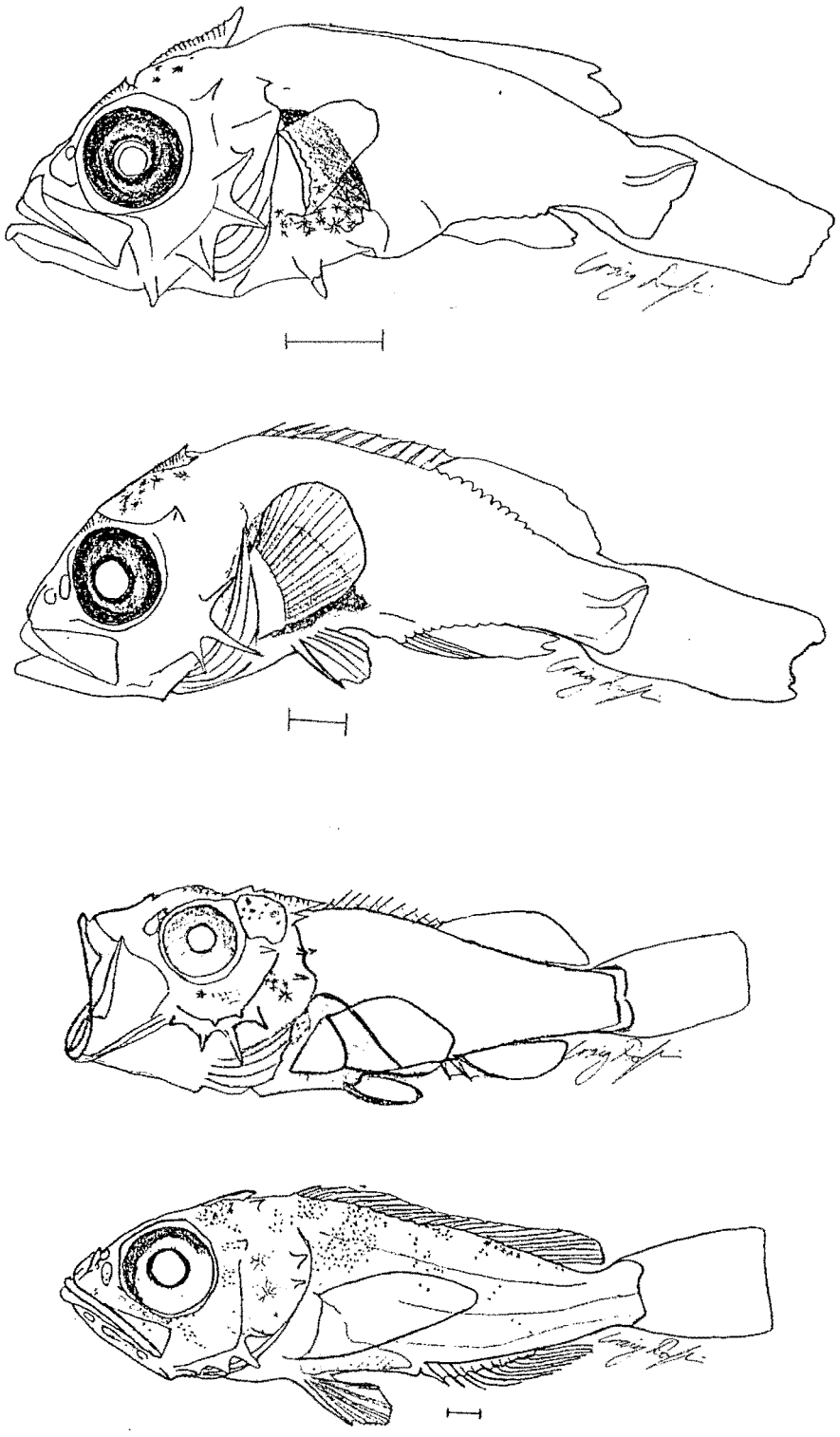

Figure 2.16 Larvae of bigeye seaperch (*Helicolenus barathri*)

a) 8.7 mm TL

b) 14.6 mm TL

c) 16.0 mm TL

d) 28.8 mm TL

Family Scorpaenidae

Scorpaena papillosus (Bloch & Schneider) **Red Scorpionfish**

Scorpaena papillosus are previously unidentified as larvae or pre-juveniles. The very similar *Scorpaena cardinalis* has been described by Elder (1966) who illustrated a 7.9 mm TL specimen, and Robertson (1973) who illustrated a late-stage larva near settlement (19.1 mm TL).

Elder (1966) suggested that *S. cardinalis* larvae have a stouter body form than *Helicolenus* sp. larvae, and that this is sufficient to separate the two genera at an early stage. Crossland (1982) considered that *Scorpaena* could be separated from *Helicolenus* on the basis of melanophore patterns found on the ventral midline of the caudal region. *Scorpaena* are thought to have a "row of melanophores along the ventral midline of the tail" (Moser et al, 1977). *Helicolenus* have "black pigmented stellate markings, one above the vent and the other midway towards the tail on the lower margin" (Graham, 1956). However, this may be useful only for very early-stage larvae as illustrations in Elder (1966) suggest that the midcaudal-ventral markings have been lost in both of these species by c. 8 mm TL. Similarly, these markings were found to be absent in *H. barathri* larvae, from this study, as small as 8.7 mm TL.

Specimens in this study (Ref. Coll. CI) were captured at night in February 1997. Specimens were encountered most often in close proximity to a fine-pebble beach. No specimens were taken on the same night, on the seaward side of a nearby rocky reef. However, one specimen was collected in this area during a 1m deep plankton tow the following day.

The smallest specimen collected was 19 mm TL and the largest was 21.8 mm TL. It is possible that the larva illustrated in Robertson (1973) is *S. papillosus* because S. *cardinalis* is otherwise not known from the east coast of the South Island. *S. papillosus* is known to be present from Kaikoura. However, it is likely that any differences between larvae of these two species are likely to be minor, since adults differ principally by the presence or absence of two coronal spines on the head (Paulin *et al.*, 1989).

Pre-juveniles of *S. papillosus* (Fig.2.17) are very easy to separate from *Helicolenus* sp. as they have a large and extremely obvious black melanophore

spot on the caudal peduncle. There are also some red chromatophores present within the characteristic spot. The gut is not enclosed in a silver peritoneum like *Helicolenus barathri*, but instead has stellate melanophores scattered across it. A few melanophores are also present above and behind the eye, and on the operculum.

Spines are very prominent on the operculum and head (parietal, nuchal, pterotic, lower posttemporal, third and fourth posterior preopercular, first and second anterior preopercular), and a bony ridge bearing spines below the eye is also present (these spines do not correspond to Moser & Ahlstrom's (1978) system of naming spines, which is based on the scorpaenid genus *Sebastes*). The flesh of the body is extremely transparent and the skeletal structure of live animals is clearly visible. All fins are well developed and fin rays have ossified (Table 2.9).

Table 2.9 Meristic counts of *Scorpaena papillosus*.

Total length	Dorsal	Anal	Pelvic	Caudal
20.5 mm	XII,10	III,5	I,5	27

Specimens were kept alive in the laboratory and proved to be easily adapted to captivity and possess voracious appetites for adult brine shrimp and other small arthropods. They were also utilised in some otolith marking trials (see Chapter 3).

Within three days of capture, all specimens had adopted adult colouration patterns and were a red-brown colour with lighter vertical bands present. Once adult colouration was present, the spines on the head were more obvious and the presence of coronal spines was sufficient to confirm the identification (Paulin *et al.*, 1989).

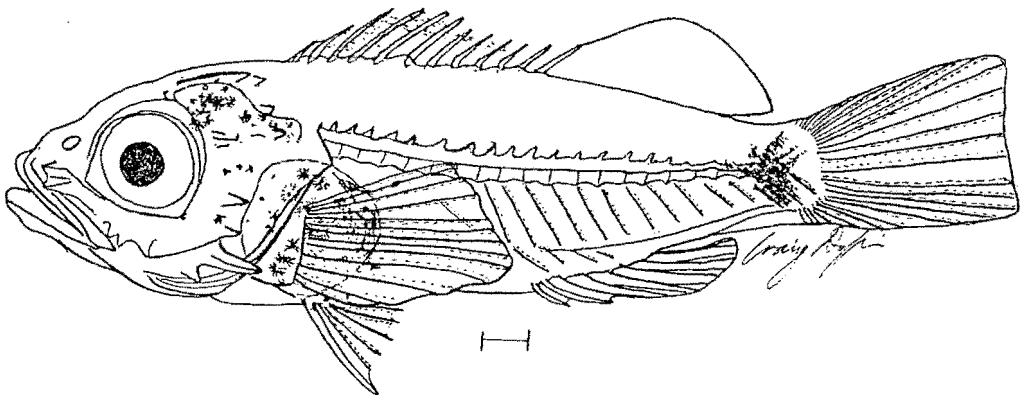

Figure 2.17 Late stage larva of *Scorpaena papillosus* 21.8 mm TL (scale = 1 mm)

Family Congiopodidae Pigfishes

Congiopodus coriaceus (Paulin & Moreland) **Deepsea Pigfish**

Three species of pigfish are found in New Zealand. Of these, two were grouped together as *C. leucopaecilus* until a review of the genus by Paulin & Moreland (1979). Differences in gill-raker counts and head profiles were considered to be distinctive enough to constitute two separate species. Of these, the deepsea pigfish (*C. coriaceus*) lives at greater depths (140 - 385m) than the shallow-water (0 - 100m) southern pigfish (*C. leucopaecilus*).

A single specimen of the alert pigfish (*Alertichthys blacki*) has been illustrated in Japan Fishery Agency (1978) (reproduced in Robertson & Mito, 1979).

Eggs of the southern pigfish (*Congiopodus leucopaecilus*) are described and illustrated in Thomson & Anderton (1921) and Robertson (1973, 1975). However, it is possible that these eggs may be *C. coriaceus* since the two species were not separated at the time of these studies. Additionally, Robertson (1974) details the developmental energetics of eggs and yolk-sac larvae of *C. leucopaecilus*.

Yolk-sac larvae have a mean length of 5.32 mm at hatching (Robertson, 1973: pg. 283). This is comparable to the size at hatching (5 - 7 mm TL) for *Congiopodus spinifer* (the only other account of larval development for this genus (Washington *et al.*, 1984)). The yolk was absorbed after 13 days and larvae were between 7.1 and 8.0 mm TL at this stage. The longest survivor after yolk absorption lasted a further 12 days and was 9.4 mm TL. Green and black pigmentation was reported to have covered most of the body by this time. Thomson & Anderton (1921) also illustrated a yolk-sac larvae at 8 days old, but no scale was given.

Only two specimens were collected in this study (Ref. Collection KA548F) and both of these were caught within two weeks in November 1996. This is consistent with Robertson's (1973, 1975) observation of occasional pigfish eggs being present in spring. These were captured in daylight plankton tows, 1m below the surface, underneath surface drift lines near the 2 km site.

The larvae are highly distinctive with huge wing-like pectoral fins which are usually fully extended and used for locomotion in combination with slow sinusoidal movements of the body. These large pectoral fins are typical of congiopodid species (Mito, 1963; Washington *et al.*, 1984).

The smallest larva (Fig.2.18 b) is pre-flexion and is 8.5 mm TL. The fin fold is undifferentiated at this size although the beginning of dorsal fin musculature is visible. The pectoral fins are large (approximately 30% TL), wing-like, and have 8 very visible fin rays. These rays are all similar at this stage. The distal edge of the pectoral fins are heavily pigmented with black, lace-like melanophores. At this stage, no pigmentation is present on the rest of the pectoral fin. Some pigmentation can be seen along the dorsal surface of the body behind the nape, and some scattered melanophores laterally on the posterior half of the body. Also, there are relatively dense concentrations of melanophores on the ventral surface of the peritoneum of the gut and the anus. The anus is almost exactly at mid-body. There is little or no pigmentation on the head (except for the eyes).

A small supra-orbital ridge, with the beginnings of a spine (supraocular), is present. The nostril is singular and immediately anterior to the orbit. Pelvic fins are not present at this stage. The length of the larva indicates that it is less than a month old (if growth rates in Robertson's (1973) lab-reared larvae are comparable). However, pigmentation on the body was very light and does not match well with Robertson's (1973) description of similar sized lab reared *C. leucopaecilus*. This may be due to differences in pigmentation between *C. leucopaecilus* and *C. coriaceus*, or an artefact of laboratory rearing.

The largest larva (Fig. 2.18 c) is 17.7 mm TL and is post-flexion. All fins are well-developed and have well-formed rays (Table 2.10). The pectoral fins are proportionally larger, and the most ventral ray of these fins is distinctly longer (65% TL) than the others (50% TL).

Pigmentation on the pectorals is far more complex than that of the smaller larva. In addition to the distal band of melanophores, there is a complex pattern of melanophore 'blotches' paired on either side of the pectoral fin rays. There are up to 5 of these melanophore 'blotch-pairs' along each fin ray. Additionally, numerous small melanophores are present along each side of the pectoral fin rays. There are melanophore 'blotches' present on the pelvic fins

also, but they are less regular in their pattern. The overall appearance of this pigmentation, when the pectoral fins are spread out, is not dissimilar to patterns seen on butterfly wings. A possible function of the pigmentation on the pectoral fins is anti-predatory by making the larvae appear larger.

Table 2.10 Meristic counts of a pigfish larva, and ranges of meristic counts for Congiopodidae and both species of *Congiopodus* in New Zealand.

	Dorsal	Anal	Pectoral	Pelvic	Gill Rakers
This Study	XVII,12	9	8	I,5	3+9
Washington *et al*., 1984 (Congiopodidae)	XVI-XX, 11-14	0-II,7-10	(8) 9	I,5	-
Paulin *et al*., 1989 (*C. coriaceus*)	XVII,11-12	8-9	8	I,5	2-4+9-10
Paulin *et al*., 1989 (*C. leucopaecilus*)	XVII,11-13	8-10	8	I,5	5-6+8-9

Pigmentation is heavy on the pectoral fin base and a distinctive dark line of melanophores is evident dorsally along the dorsal fin base. Numerous small melanophores are scattered across the body, and dorsal and anal fins, but the overall impression is of transparency.

The beginning of snout protrusion is noticeable at this stage, but the head is dominated by two large spines on each side of the head. The most obvious spine (supraocular) is immediately above, and anterior to, the orbit of the eye. This is heavily pigmented, and the pair of spines vaguely resemble horns. The second major spine (parietal(?)) is present beside the dorsal fin origin and is only lightly pigmented. A third small spine (pterotic) is also present. This is directed backwards from the upper operculum. A bony ridge extends back from above the eye and terminates at this spine.

In comparison to the larval alert pigfish illustrated in Robertson & Mito (1979) it is clear that these species are easily separable. Although both have large pectoral fins, the deepsea pigfish's are larger proportionally and have a far more elaborate pattern of pigmentation. The presence of large, heavily pigmented 'horns' also clearly separates the species. Similarly, larger pelvic fins, high anterior dorsal fin, and overall body shape serve to distinguish *C. coriaceus* from *A. blacki.*

Assuming that Robertson's (1973, 1975) pigfish eggs are *C. leucopaecilus*, it is possible that the southern pigfish and deepsea pigfish differ in pigmentation

from an early stage. However, the difference in pigmentation may also be an artefact of captive rearing. No significant increase in pigmentation occurred during the three weeks of captivity that the larger of the two larvae experienced (although the dorsal fin grew noticeably). This suggests that captivity may not be responsible for the pigmentation observed in Robertson's (1973) study. This needs further investigation. Gill raker counts (Table 2.10) were the critical character in identifying the larger of the two larvae as *C. coriaceus*. The identification of the smaller larva is based on the timing of its capture, and its similarity to the larger larva.

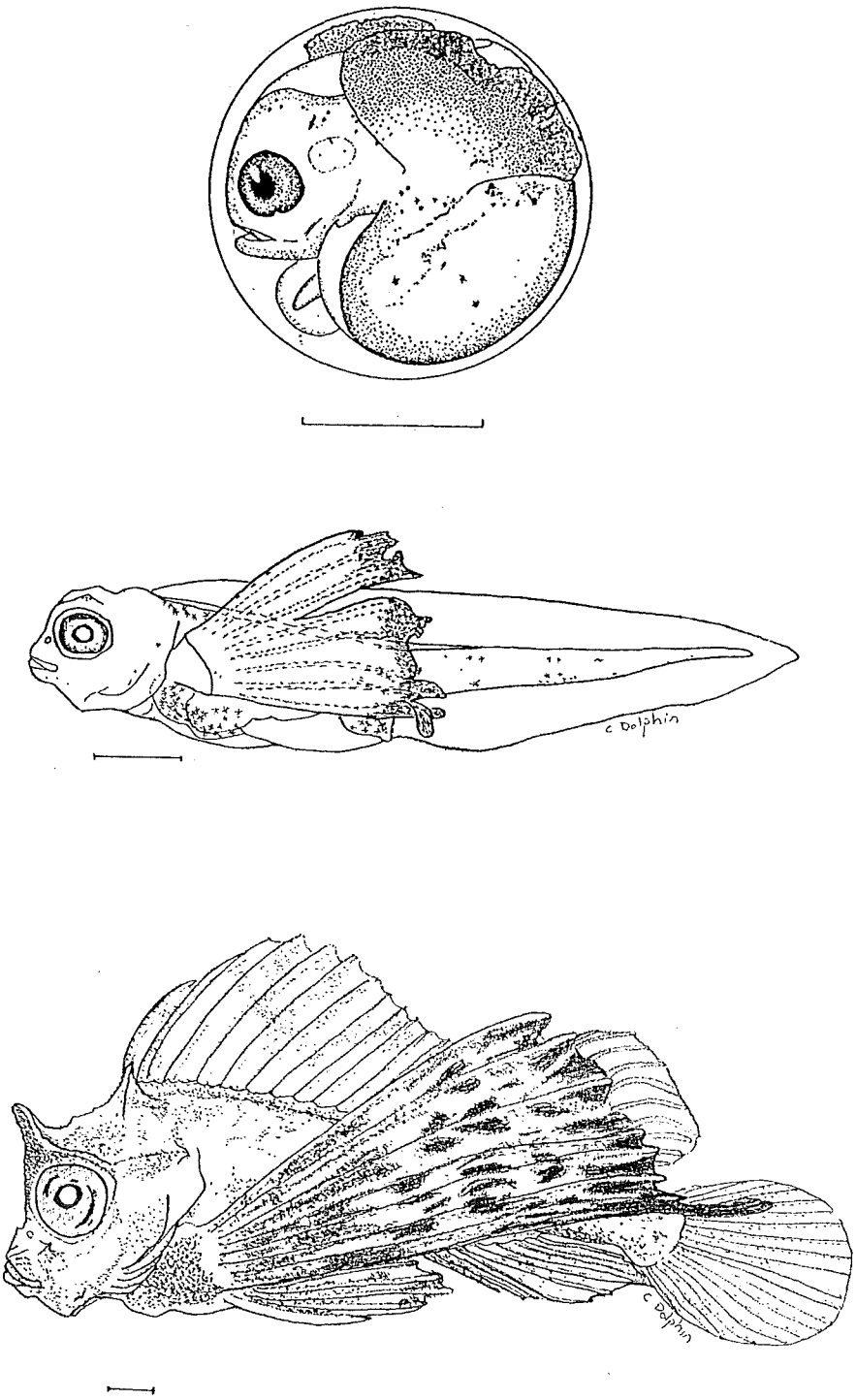

Figure 2.18 Development of the deepsea pigfish (*Congiopodus coriaceus*)
(scale = 1 mm)
a) Reproduced from Robertson (1975)
b) 8.5 mm TL
c) 17.7 mm TL

Family Triglidae

Chelidonichthys kumu (Lesson & Garnot) **Red Gurnard**

Red Gurnard have been fully described as both eggs and larvae (Anderton, 1906; Thomson & Anderton (1921); Mito, 1963; Robertson, 1973, 1975). Eggs are described and illustrated in Robertson (1975) as spherical with a diameter from 1.3 to 1.5 mm, a non-segmented yolk, and a single oil droplet (Ø 0.275 mm). Also, the embryo and yolk are spotted with regularly spaced melanophores. This description was found to be very good for distinguishing red gurnard eggs from other eggs. However, the illustration in Robertson (1975) does not show the melanophore spots on the yolk. Robertson (1975) states that the eggs occur in coastal waters during summer and autumn. Elder (1976) reports that red gurnard spawn year round in the Hauraki Gulf with a peak of spawning activity from December to March.

Eggs in this study were collected occasionally in daylight plankton tows at a depth of 1m below the surface, primarily in South Bay and near the mouth of the Kowhai River, in January and early February 1997. The eggs were usually well advanced in development and hatched the same day as capture.

Larvae (Ref. Collection CS) were captured in early summer (December 1995) in daylight plankton tows at the surface in South Bay.

The early stage larvae of red gurnard have been described and illustrated by Mito (1963). The larvae in this study that hatched from captured eggs were identical to those illustrated in Mito (1963), confirming the identification. However, differences were found in total lengths at similar stages of development.

For example, a day after hatching red gurnard larvae were measured and are 4.6 mm TLL (Fig. 2.19 a). This stage of development is comparable to that illustrated in Mito (1963) with a total length of 3.7 mm given. It is likely that Mito (1963) illustrated larvae which had been preserved in formalin and shrinkage due to this would explain the observed differences in length.

At 4.6 mm TLL the larvae have a small pectoral fin and a semicircular pattern of melanophores can already be seen on it. The fringes of the dorsal and anal finfolds have a series of black melanophores and some yellow-green pigmentation present from the cranium to the caudal peduncle and from behind

the anus to the caudal peduncle. The yolk sac is still present and retains its characteristic pattern of regularly spaced melanophore dots. These are yellow-green in colour with a central black spot. The body is pigmented with several stellate black melanophores interspersed with yellow-green pigmentation. This extends as far back as the caudal peduncle.

Kingsford & Barrington (1986) reproduces Mito's (1963) illustrations along with a larva drawn by Roper (3.9 mm TL; 1981), and a late-stage larva (14.5 mm TL) reproduced from Robertson (1973). Roper's (1981) illustration is of a larva c. 5 days old (by comparison to stages of growth observed in this study) and corresponds to a total live length of 5.39 mm (cf. Roper's given TL of 3.9 mm).

Young larvae ate rotifers voraciously. The longest period of survival from hatching in this study was 10 days. The last larva had started feeding on brine shrimp nauplii, but seemed to have trouble catching enough of them to meet its nutritional requirements (only two were seen in the gut of the larva). It is suspected that brine shrimp nauplii are not a suitable food item for these larvae when rotifers are no longer in the preferred food size range. It may be necessary to find an intermediate sized prey item for red gurnard larvae. At 10 days the larva is 5.16 mm TL (measured after *rigor mortis* but prior to preservation in 95% ethanol). The reduction in size is probably an artifact of death and poor nutrition over the last couple of days of life.

The larva at 10 days (Fig. 2.19 b) has a much larger pectoral fin than at hatching, and this has a far more elaborate pattern of melanophores. The previously yellow-green pigmentation has become distinctly green. It is more widespread across the head, gut, and the anterior portion of the dorsal finfold. Pigmentation on the fringes of the dorsal and anal fin folds has become much reduced with only a series of small green pigment patches present at approximately mid-height on the finfolds. Body pigmentation is now restricted mainly to a series of black melanophores along the ventral midline. No green pigmentation is present on the body posterior to the pectoral fins. The head of the larva is well developed with the characteristic snout of adult gurnard becoming evident.

Wild-caught larvae were all post-flexion. At 10.8 mm TL (Fig.2.19 c) the larvae are very distinctive with large pectoral fins and prominent head spination.

Prominent spines are visible immediately above the orbit (postocular), along the lower operculum (first to fifth posterior preopercular, first and second anterior preopercular), and dorsally at the nape (parietal, nuchal). Pigmentation is brown-red in colour. The large pectorals are pigmented similarly to those of lab-reared larvae, although the melanophores are darker and more spread out. Some pigmentation is also present on the crown of the head and scattered across the operculum. The gut peritoneum is pigmented heavily with stellate melanophores. The lower three rays of the pectoral have not yet begun to separate from the rest of the fin. The dorsal and anal fins have fin rays present, although these are not yet countable without clearing and staining techniques. The pelvic fins have appeared and are well developed. The caudal fin rays are well developed.

By 13.5 mm TL (Fig.2.19 d) the armature on the head has increased with a lateral row of spines appearing below the eye (lower infraorbital 1-5). A pair of spines has developed on the snout above the nasal area (nasal). Also, new spines have appeared at the pre-opercular edge (third anterior preopercular), immediately posterior to the top of the gill opening (supracleithral), and behind the eye (pterotic). Pigmentation has increased on the pectoral fins and across the head and operculum. Melanophores have also appeared on the pelvic fins and the anterior part of the body. A few melanophores can be seen scattered sparsely across the rest of the body and the first dorsal fin. All fin rays are fully ossified. The lower three spines of the pectoral fins are still non-differentiated from the rest of the fin.

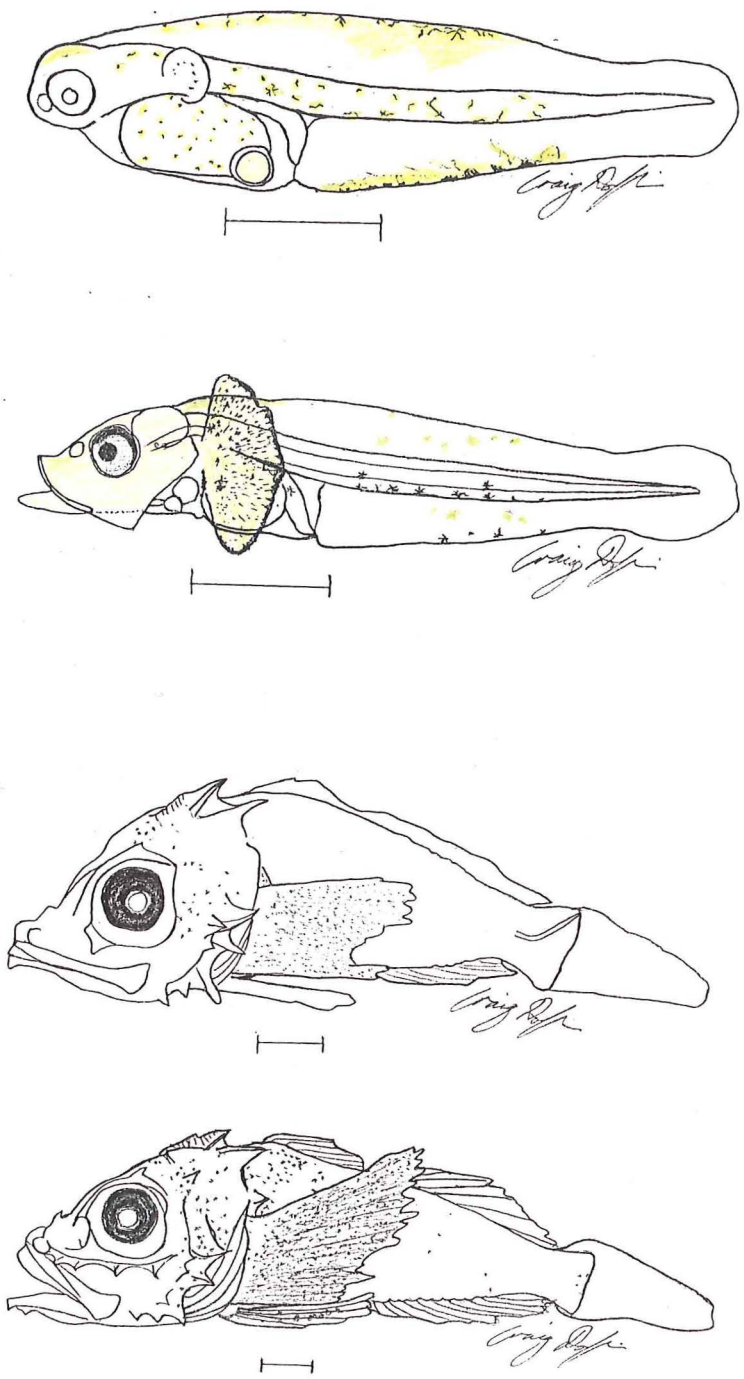

Figure 2.19 Development of the red gurnard (*Chelidonichthys kumu*)

(scale = 1 mm)

a) 4.6 mm TL (1 day)

b) 5.16 mm TL (10 days)

c) 10.8 mm TL

d) 13.5 mm TL

2.14 Order Perciformes

Family Serranidae

Lepidoperca sp.A (Paulin *et al.*) **Orange Perch**

Serranid larvae have not been described from New Zealand waters. Robertson (1975) described the eggs of *Lepidoperca* sp A (syn. *Anthias pulchellus*) as having a diameter between 0.775 and 0.925 mm. They possess a single oil droplet with a diameter of between 0.175 and 0.20 mm. Robertson noted that they are present during summer and autumn in the Cook Strait - Kaikoura area.

Specimens in this study (Ref. Collection BA) were collected as eggs. The eggs had a mean diameter of 0.84 mm (n=3; 0.77 - 0.88 mm) and a mean oil droplet diameter of 0.19 mm (n=3; 0.18 - 0.20 mm). They were captured at the surface in daylight plankton tows in South Bay during late November. The eggs were kept in the laboratory until hatching. Yolk-sac larvae did not survive more than 24 hours even though yolk-sac absorption was not completed. No serranid larvae were captured in plankton tows.

All eggs were at an early stage of development when captured (Fig. 2.20 a) with the blastodisc not yet covering half of the yolk. The oil droplet is present and highly visible.

Twenty hours later (Fig. 2.20 b) the embryo is visible with light pigmentation present on the anterior and posterior ends of the dorsal surface. The eyes are not visible at this stage.

After another 24 hours the eyes have become visible (Fig. 2.20 c), and pigmentation has spread from both anterior and posterior regions. Small melanophores are scattered along the length of the embryo. In particular, some are present around the eye orbits.

Hatching had occurred within the next 24 hours and the yolk-sac larvae had a mean length of 2.2 mm (n=2) when measured alive. The newly hatched larvae (Fig. 2.20 d) are characterised by the placement of the oil droplet at the anterior end of the yolk. Also, the origin of the dorsal finfold is well back from the head region, originating above the yolk at approximately 25%TL. The finfold is visibly constricted around the caudal peduncle. Pigmentation remains light on the head and anterior half of the body. Melanophores on the caudal peduncle have begun to darken and spread.

Within 24 hours of hatching, pigmentation had increased markedly (Fig. 2.20 e). Stellate melanophores extended down from the dorsal midline and up from the ventral surface. Extensive pigmentation was present dorsally on the head and stellate melanophores could also be seen around the oil droplet. The yolk was about 60% absorbed. The gut had not yet formed fully, and the anus was marked only by a thickening in the anal finfold behind the yolk. Unfortunately all the larvae died and only one was recovered prior to consumption by scavenging protozoans. This larva measured 2.2 mm TL (n=1).

The general morphology of the yolk-sac larvae conforms well with the generalised serranid (anthiinae) yolk-sac larvae in Kendall, Jr. (1984, pg. 499). This supports the identification based on the egg sizes and characteristics. Furthermore, only four species of serranid have been recorded from Kaikoura (Edward Percival Field Station teleost species record). Of these, only two (*Lepidoperca* sp A and *Ellerkeldia huntii*) are common in the area.

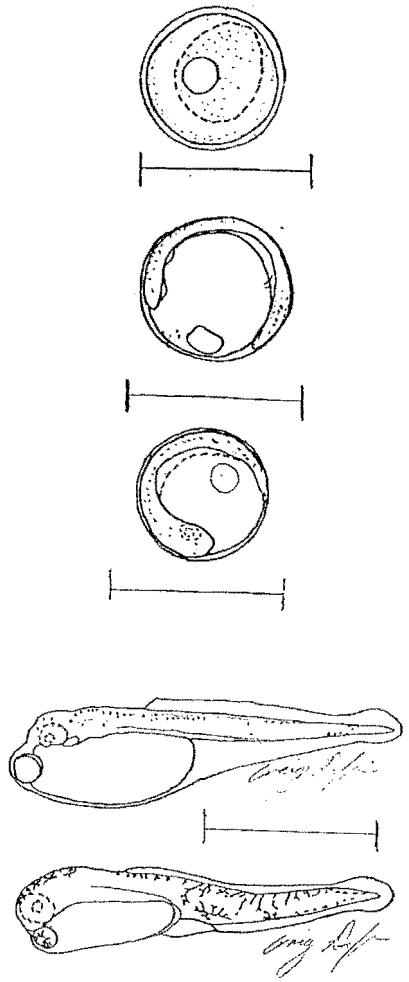

Figure 2.20 Early development of orange perch (*Lepidoperca* sp A)
(scale = 1 mm)
a) development at capture
b) after 20 hours
c) after 44 hours
d) Yolk-sac larva (2.1 mm TL)
e) 1 day old larva (2.2 mm TL)

Family Acanthoclinidae

Acanthoclinus fuscus (Jenyns) **Olive Rockfish**

Rockfishes are small littoral species which are widespread around New Zealand. They are demersal egg layers. The male exhibits parental care of the developing embryos by staying with the egg mass and maintaining a flow of water across the eggs (by fanning with the pectoral fins). There are 5 species found in New Zealand (Hardy, 1984) although 4 of these have historically been classified as one species (*A. trilineatus*).

Elder (1966) illustrated a developmental series from 4.6 mm - 12.3 mm TL. Development of the eggs and yolk-sac larvae of *A. fuscus* (syn. *A. quadridactylus*) has been described by Jillet (1968b). Frentzos (1980) contains photographs of a developmental series of larvae from 4.4 mm to 11.2 mm TL. Roper (1981) illustrated a 5.6 mm TL larva, and Crossland (1982) illustrated a 9.9 mm TL specimen.

Larvae in this study were captured near St Kilda's rocks in mid-January 1996, in surface plankton tows. Many of these were alive when removed from the net and some were reared to maturity in the laboratory. They were fed on a diet of brine shrimp nauplii, supplemented with mosquito larvae and white worms. Larvae did not rest on the tank bottom during captivity but hovered above it with the anterior of the larvae sloping downwards on an angle approximately 20% below horizontal. At c. 10 mm TL the larvae settled and started to hide beneath any available cover.

The smallest larva captured was 6 mm TL. The pelvic fin has already appeared below the pectoral fin insertion (Fig. 2.21 a). This agrees with photographs in Frentzos (1980), but contrasts with Elder's (1966) illustrations which suggest that pelvic fins have not appeared by 8 mm TL. Flexion has occurred which agrees with Jillet (1968b) who observed flexion to occur by 5.5 mm TL. Pigmentation has increased anteriorly on the abdomen. The caudal peduncle remains non-pigmented.

At 8 mm TL (Fig. 2.21 b) pigmentation is more widespread and fin rays have begun to ossify. The caudal peduncle remains non-pigmented, as does the nape and the ventral part of the head.

By 10 mm TL (Fig. 2.21 c) the body pigmentation is darker but the caudal peduncle remains non-pigmented. No pigmentation is seen on any fins at this stage. This agrees with Crossland's (1982) illustration. A pale stripe is present along the top of the head.

By 12.8 mm TL (Fig. 2.21 d) pigmentation is starting to spread onto the caudal peduncle and the lower part of the head. Also, a metallic-gold sheen is present along the flanks of live specimens. This vanishes in 95% ethanol or formalin. There is still no pigmentation on the fins at this stage. Jillet (1968b) suggests that rockfish larvae settle from a length of 10 mm TL and are present in the plankton for less than three months.

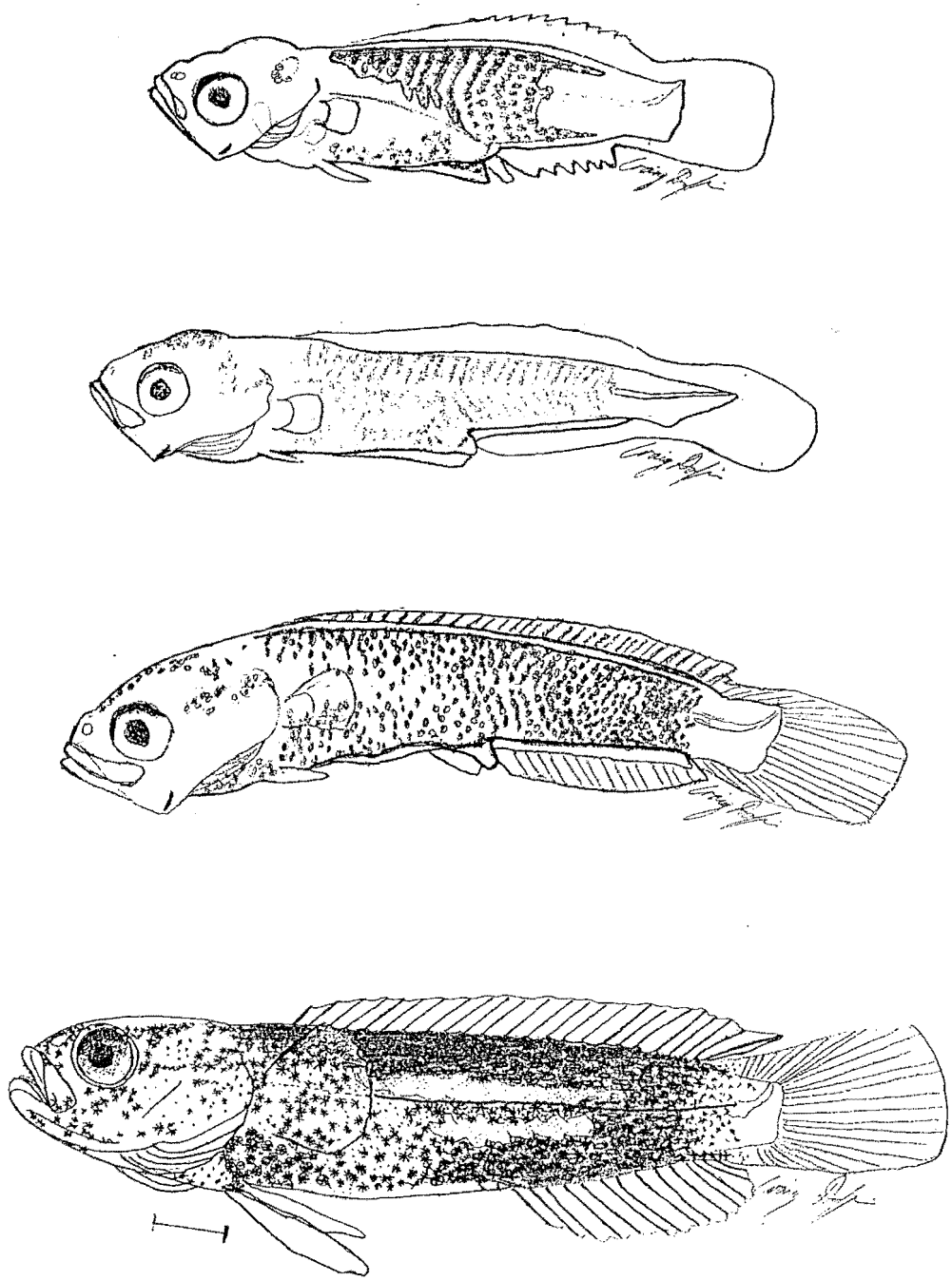

Figure 2.21 Development of *Acanthoclinus fuscus*

(scale = 1 mm)

a) 6.0 mm TL

b) 8.0 mm TL

c) 10.0 mm TL

d) 12.8 mm TL

Family Acanthoclinidae

Taumakoides rua (Hardy) **Little Rockfish**

Historically *T. rua* was included within a complex of species given the name *Acanthoclinus trilineatus.* This situation was reviewed by Hardy (1984) with four new species and a new genus being described as a result. Frentzos (1980) features photographs of a complete developmental series of *A. trilineatus.* Crossland (1981) illustrated a 10.0 mm TL specimen of *A. trilineatus,* and Roper (1981) illustrated a 5.1 mm TL specimen.

Four larvae of this species were captured in late January 1997, on the south side of Point Atia (Shark's Tooth reef) in daytime plankton tows 1m below the surface.

The smallest larva captured was 4.27 mm TL (Fig. 2.22 a). This is smaller than the mean length at hatching (4.75 mm) given by Jillet (1968b) for *Acanthoclinus fuscus* (syn. *A. quadridactylus*). The general pattern of melanophores on the body is similar to that illustrated by Elder (1966), Frentzos (1980), and Roper (1981). By contrast, *A. fuscus* appears to have comparatively little pigmentation present on the nape of the neck (Jillet, 1968b). The pelvic fins are not yet present.

Three larvae which were c. 13 mm TL (Fig. 2.22 b) were also captured. No larvae intermediate between these extremes were recognised.

These are similar to *A. fuscus* larvae, but pigmentation on the posterior part of the dorsal and anal fins is present. This can also be seen in Crossland's (1982) *A. trilineatus* individual. Also, eye pigmentation is distinctive because two dark lines (one vertical, one horizontal) divide the eye into four.

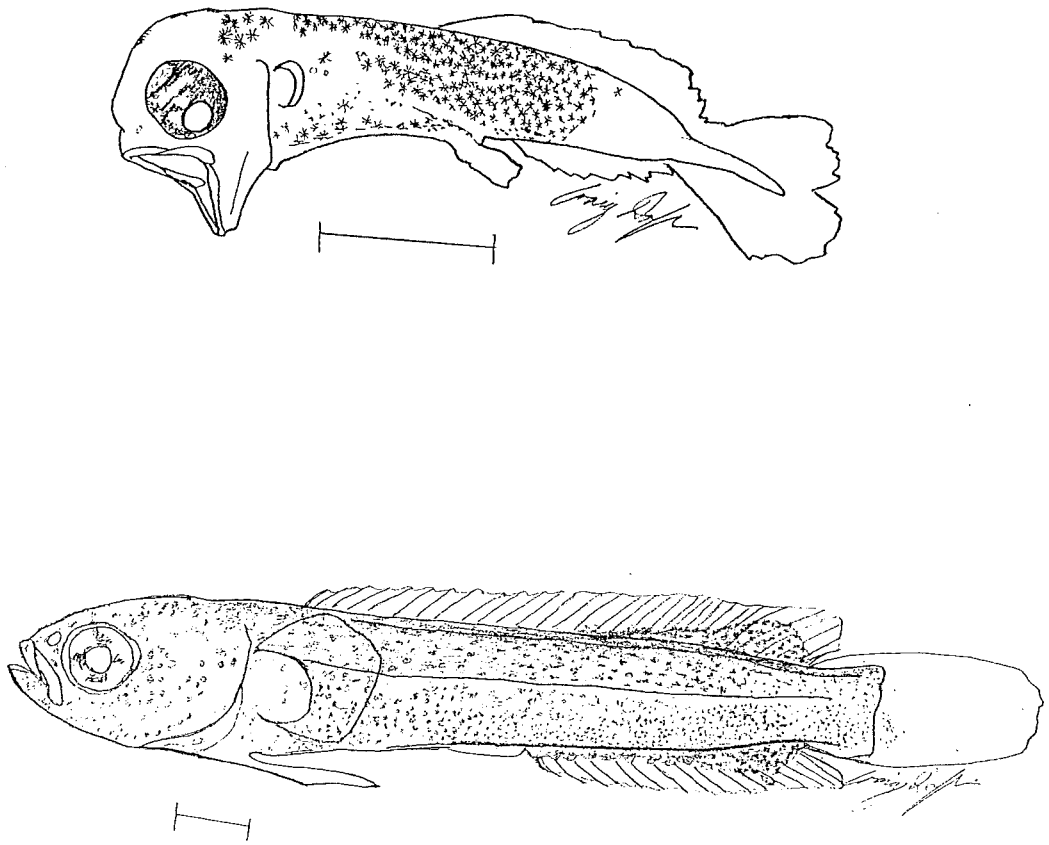

Figure 2.22 Larvae of the little rockfish (*Taumakoides rua*)

(scale = 1 mm)

a) 4.27 mm TL

b) 13.64 mm TL

Family Latrididae

Mendosoma lineatum (Guichenot) **Telescope Fish**

Eggs of telescope fish have been described by Robertson (1973, 1975) based on a single egg taken from a spent female speared at Stewart Island. Additional planktonic eggs that Robertson (1973) described as being identical ranged in size from 1.175 to 1.325 mm diameter with a wide perivitelline space of 0.125 mm. Between 3 and 9 greenish oil droplets were present and the yolk was non-segmented. This was altered in Robertson (1975) so that the range of egg diameters was 1.175 - 1.25 mm, and the number of oil droplets was between 2 and 7. Robertson (1975) stated that these eggs were present in low abundances from spring to autumn on the east coast of the South Island. Crossland (1981, 1982) described a very similar egg (1982, pg.45, unidentified egg 3) from the outer Hauraki Gulf and Bay of Islands, during October 1977 and 1978. The size range of Crossland's (1982) egg is smaller (1.02 - 1.12 mm) than that given by Robertson (1975).

Nothing is presently known of the larval stages of any latrid fish in New Zealand.

Specimens in this study (Ref. Collection BD) were collected as eggs in daylight plankton tows at a depth of 1m below the surface in South Bay, during late October 1996. Larvae were hatched out successfully, but died after 8 days.

Six eggs were captured on 28/11/96 and varied in size from 1.18 - 1.27 mm diameter. They had 3 - 8 olive-green oil droplets with a maximum diameter of 0.09 mm. However, the perivitelline gap is smaller (0.04 - 0.07 mm) than indicated by Robertson (1975). It is possible that these eggs belong to another latrid, such as the blue moki *Latridopsis ciliaris* which is more abundant at Kaikoura than telescope fish.

The eggs were at different stages of development when captured. The earliest stage eggs (Fig. 2.23 a) had less than half of the yolk covered by the embryonic shield. The most advanced eggs (Fig. 2.23 b) had embryonic larvae visible, with well-formed eyes and some yellow pigmentation on the posterior half of the body. Development from the later stage of these eggs to hatching took three days. During this time, the pigmentation on the body increased and extended forward to include the head (Fig. 2.23 c, d). The day prior to hatching,

some large melanophores could be seen along the dorsal midline and many smaller melanophores were present along the ventral midline (Fig. 2.23 e). The yellow pigmentation had begun to reduce but was still evident along the dorsal and ventral midlines of the posterior half of the body, and around the eyes.

Yolk-sac larvae are 4.7 mm TLL (n = 1) upon hatching and have c. 7 melanophores along the dorsal midline of the body (Fig. 2.24 a). The most anterior of these is forward of the anus and above the posterior part of the yolk sac. Yellow pigmentation surrounds each of these melanophores. Yellow pigment is also present immediately behind the eye and along the ventral midline of the body. This extends onto the sides of the body directly opposite the posterior three melanophores on the dorsal midline. This results in a distinct yellow 'patch' on the caudal peduncle, and some smaller areas of yellow pigmentation anterior to this. The oil droplets are concentrated in a series found posteriorly in the yolk sac. Some very fine melanophores are present on the yolk sac. Numerous contracted melanophores are present on the ventral midline, from above the gut to the caudal peduncle. The jaws are not yet functional and the pectoral fins are very small.

After four days the gut is formed, and the jaws are fully developed and functional. The pectoral fin is larger than at hatching. Pigmentation is unchanged except that yellow pigmentation is now restricted to the posterior third of the body, and the most anterior dorsal melanophore is now above the anus. The very fine pigmentation on the yolk sac has developed into stellate melanophores along the ventral profile of the gut. Most larvae were able to capture and ingest rotifers and seemed to be developing well. However, one of these larvae did not begin feeding (Fig. 2.24 b) and died.

At 8 days old the larvae were 6.1 mm TLL (n = 1) and feeding rapidly. However, after a period of starvation all the larvae died and were consumed by scavenging protozoans before they could be retrieved.

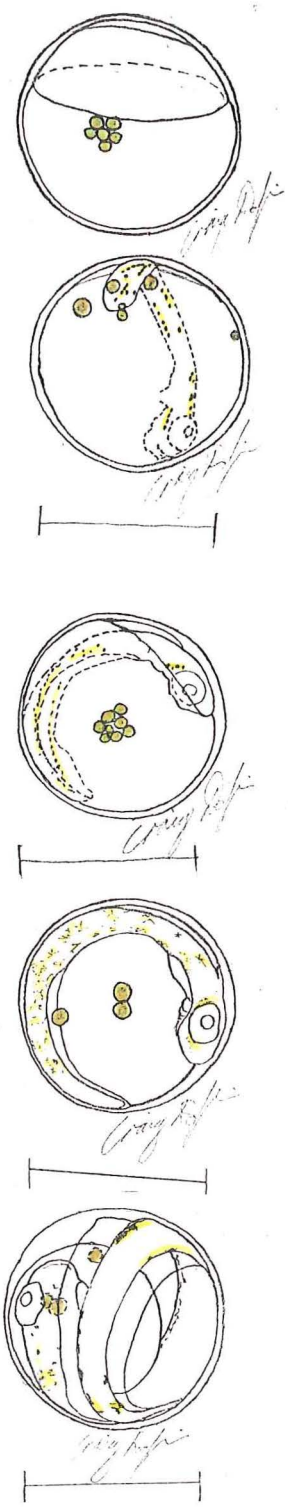

Figure 2.23 Egg development of *Mendosoma lineatum*

(scale = 1 mm)

a) early stage eggs at capture

b) later stage eggs at capture

c) one day after capture

d) two days after capture

e) 3 days after capture

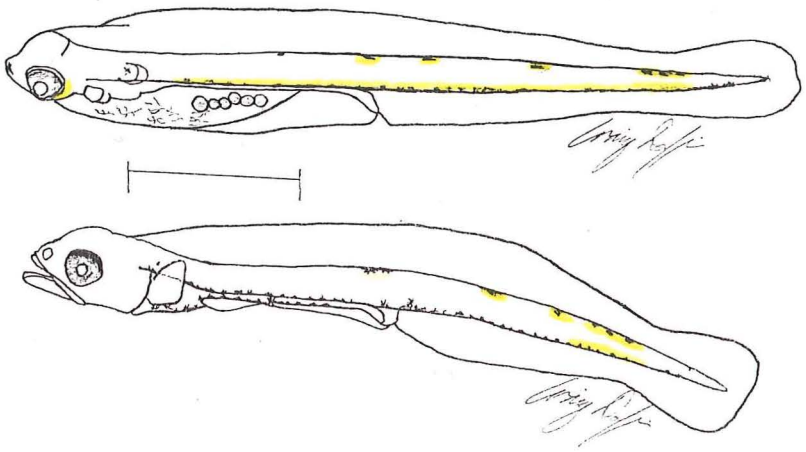

Figure 2.24 Early larval development of *Mendosoma lineatum*

(scale = 1 mm)

a) After hatching 4.67 mm TLL

b) Non-feeding specimen after 4 days

Family Mugilidae

Aldrichetta forsteri (Cuvier & Valenciennes) **Yellow-Eyed Mullet**

Eggs of this species have been described by Cassie (1955), and also described and illustrated by Crossland (1981). They range in diameter from 0.84 to 0.93 mm and possess between 3 and 13 oil droplets. Manikiam (1963) described eggs as having a diameter c. 0.5 mm but these were from gonads of adult fishes and may not have been fully ripe. Larvae are not fully described or illustrated, with the single exception being a 10.5 mm TL individual illustrated in Crossland, and reproduced in Kingsford & Barrington (1986).

No eggs were recognised in this study. Larvae and juveniles were captured during summer (February and March) of 1996 and 1997. These were caught in surface plankton tows at South Bay, 4 km, and 6 km sites. Small larvae did not survive capture but juveniles occasionally survived net turbulence.

Specimens caught in 1996 (Ref. Collection AB), and those caught in 1997 (Ref. Collection CJ) differed greatly in colouration. Specimens caught in 1996 were very dark in colour with densely distributed melanophores evident. A metallic-silver sheen was visible laterally at each myotome. In 1997, however, larvae were silver/grey in colour with fine speckles of darker pigment across the body surface. Fin ray counts were the same for both morphotypes.

The smallest individual captured was 6 mm TL. At this stage the pelvic fins have not yet appeared. The finfold is continuous from the dorsal origin (at approximately mid-body) to the anus. The relative eye diameter is large (Table 2.11). Flexion has occurred and some ossification of caudal fin rays is evident.

By 7.2 mm TL (Fig. 2.25 a), the abdominal pelvic fins are present and dorsal and anal finfolds are separated from the caudal fin. The relative eye diameter is still large (Table 2.11). Muscle blocks at the base of the second dorsal fin are visible but the first and second dorsal fins remain connected. Fin rays are barely visible and weakly ossified in the second-dorsal and anal fins.

At 11.5 mm TL (Fig. 2.25 b) the first dorsal fin and second dorsal fin outlines are evident, but a thin section of finfold still links the two together. The eye is smaller and fin rays in the anal fin and second dorsal fin are present (Table 2.11).

The dorsal fins have completely separated by 12.8 mm TL (Fig. 2.25 c) and the relative eye size continues to decline. Meristic counts are presented in Table 2.11.

By 18.6 mm TL (Fig. 2.25 d) the eye has decreased in relative size to 30% HL. This compares to an adult eye-size of approximately 25% HL (Paulin *et al.*, 1989).

Development of *A. forsteri* appears to be much slower than in other mugilids. DeSylva (1984) commented that mullets form their first-dorsal fin rays by 5.4 mm TL. In *A. forsteri*, however, the first-dorsal fin rays are not evident until much later (c. 12 mm TL). The order of fins, in which fin ray formation occurs, is the same (caudal > second dorsal & anal > first dorsal) as other mugilids (DeSylva, 1984).

Table 2.11 Meristic counts from yellow-eyed mullet of different lengths.

Total Length	Dorsal	Anal	Pelvics present	Eye Diameter/HL
6.0 mm	-	-	-	44%
7.2 mm	-	-	yes	45%
11.5 mm	? + I,9	III,12	I,5	38%
12.8 mm	IV + I,9	III,12	I,5	36%
18.2 mm	IV + I,9	III,12	I,5	30%
Adult*	IV + I,7-9	III,12	I,5	25%

* from Paulin *et al.*, 1989

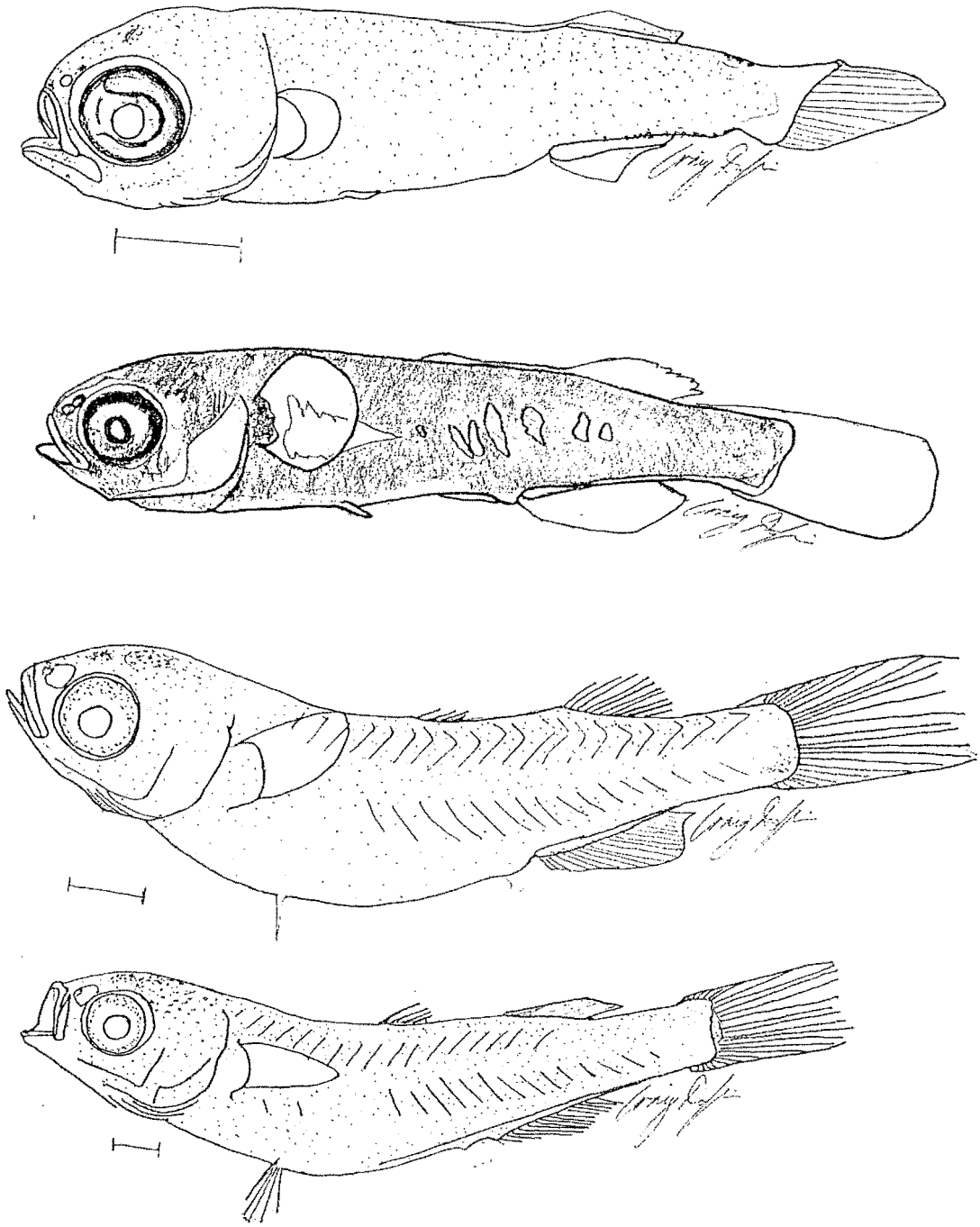

Figure 2.25 Development of yellow-eyed mullet (*Aldrichetta forsteri*)

(scale = 1 mm)

a) 7.2 mm TL (1997)

b) 11.5 mm TL (1996)

c) 12.82 mm TL (1997)

d) 18.6 mm TL (1997)

Family Labridae

Notolabrus celidotus (Bloch & Schneider) **Spotty**

Spotty eggs are described by Robertson (1973, 1975) as being between 0.75 and 0.8 mm diameter with a single oil droplet that has a diameter of 0.15 mm. Yolk sac larvae of this species are unknown but Robertson (1973) reported that sperm from *Notolabrus fucicola* were able to fertilise eggs of *N. celidotus*. Size at hatching of the hybrid larvae was reported to be 1.66 mm. All of the hybrid larvae died before yolk-sac absorption was complete, and they were 2.55 mm TL at this stage.

Descriptions and illustrations of larval spotties are found in Elder (1966), Robertson (1973), Roper (1981), Crossland (1981, 1982), and Kingsford & Barrington (1986). Photographs of larval spotties are found in Frentzos (1980) and Thomson (1983). Roper (1981) illustrated a 5.5 mm TL spotty larva which he described as "characterised by a single, punctate melanophore on ventral contour, and sometimes another, opposite on dorsal contour." This characteristic pattern is visible in Crossland's (1981) illustration of a 13.2 mm TL specimen, but not in Elder's illustrations of larvae from 9 mm TL and up. Photographs from Frentzos (1980) and Thomson (1983) are not clear enough for comparison. Elder (1966) described live spotty larvae as "colourless except for a yellow bar across the caudal peduncle and red spots about the mouth and gut".

Larvae in this study were captured in daylight surface plankton trawls at South Bay and near the mouth of the Kowhai River. These proved to be relatively hardy and many were viable after removal from the net. Six were reared in the laboratory from a length of c. 13 mm TL and were kept for over 5 months under ambient water temperature conditions. Larvae were encountered in mid summer (January and February) of 1996 and 1997. Elder (1966) reported that he captured larvae of *P. celidotus* in Wellington harbour, between November and January, whilst Crossland (1981) found larval spotties in northland waters between October and early December. This suggests that spotties may spawn earlier in warmer northern waters. However, Robertson (1973) found spotty eggs were present in Otago waters from August through to December. This is difficult to compare with Crossland's (1981) study because

he did not sample during the late winter months. Eggs which match Robertson's (1975) description for *P. celidotus* were also taken in this study and hatched out in the laboratory. These were mainly collected in November. However, no certain identification could be made since four labrid species are present in the area, and other fish species may also have similar eggs (Crossland, 1981). The most likely candidate amongst the variety of larval types which hatched out of this collection of eggs is presented later as Unidentified species BH (Appendix B).

Spotty development is known from 5.5 mm TL upwards. At the smallest size, flexion has occurred but fin ray ossification is not yet apparent. Pigmentation is restricted to a stellate melanophore on the dorsal surface of the gut peritoneum and another small melanophore on the ventral contour. Another melanophore may, or may not, be present opposite this on the dorsal contour. The presence or absence of yellow pigmentation, present in live specimens, is not recorded by Roper (1981) who illustrated all specimens after preservation in formalin. Elder (1966) reported that this pigment was lost very rapidly in preservation.

Elder (1966) illustrated spotty larvae from a size of 9 mm TL upwards. His 9 mm TL specimen has fin rays present in dorsal, anal, and caudal fins. The pelvic fins are not yet evident. At 10.7 mm TL the only apparent change is that the origin of the dorsal rays has extended forward to immediately behind the posterior edge of the operculum.

The smallest spotty larva caught in this study was 12 mm TL (Fig. 2.25 a). At this size the pelvic fins are present and dorsal and anal fins are well developed with fully ossified fin rays. Fin ray counts were (Dorsal) IX,10, (Anal) III,9, (Pelvic) I,5, and (Caudal) 28. Freshly caught individuals have obvious orange-yellow pigment patches present on the ninth and tenth post-anal myotomes. Also, orange pigment spots are present on the lower lip, below the pectoral fin insertion (anterior to the pelvic fins), and several are present on the sides forward of the anus. A small melanophore is present on the ventral contour of the caudal peduncle at the tenth post-anal myotome. No dorsal-counterpart was present in any larvae examined in this study. Orange pigmentation disappeared within 2 days of preservation in 2% buffered formalin.

Wild larvae as large as 14 mm TL (Fig. 2.26 b) were found to have these characters present, although the melanophore on the ventral contour was not observed in individuals larger than 12 mm TL. However, this can be seen in Crossland's 13.2 mm TL individual, so it is unlikely that this is consistent between individuals.

Larvae kept alive in the laboratory began to lose the orange pigmentation within a few days and developed a light green colour with poorly defined brown bands across the head. Indistinct 'blotches' of brown pigmentation are present on the sides, and at the bases of the dorsal and anal fins. The first 'blotch' is present at the origin of the dorsal fin. The second and third 'blotches' on the dorsal fin base (approximately mid-fin, and immediately anterior to the dorsal fin termination) are directly opposite the two 'blotches' on the anal fin.

By 16 mm TL (Fig.2.26 c) the colouration of these larvae is similar to the adult colouration of banded wrasses (*P. fucicola*). It was not until larvae reached a size of at least 25 mm TL that the diffuse pigment blotches began to coalesce to form the characteristic 'spot' of juvenile spotties. However, it is probable that the colouration apparent in lab-reared larvae (this study; Elder, 1966, pg. 31, Figure 3) is somewhat artificial. During prawn collecting in the Avon-Heathcote Estuary, two labrid pre-juveniles (Fig. 2.26 d) were collected in a fine seine net immediately below the low tide zone in mid-April 1997. These were living in close association with sea lettuce (*Ulva* spp.) and were a uniform lime-green colour. The most likely identification for these specimens is *N. celidotus* which is the most common labrid in the estuary. Preservation in alcohol reveals that the pigment 'blotches' at the fin bases are present, but hard to see in estuarine pre-juveniles.

Duffy (1989) found that *N. celidotus* larvae settle out of the plankton in Kaikoura from c. 15 mm TL, from December through to March, into *Cystophora* spp. plants in the lower fringe of the littoral zone. It seems that larvae also settle amongst *Ulva* spp. in channels and pools near the low tide level where their vivid green colouration provides good camouflage. When they have developed further in this environment, the young spotties adopt the more normal colouration of juveniles and move down the shore and form juvenile schools (Choat, 1962; Jones, 1980).

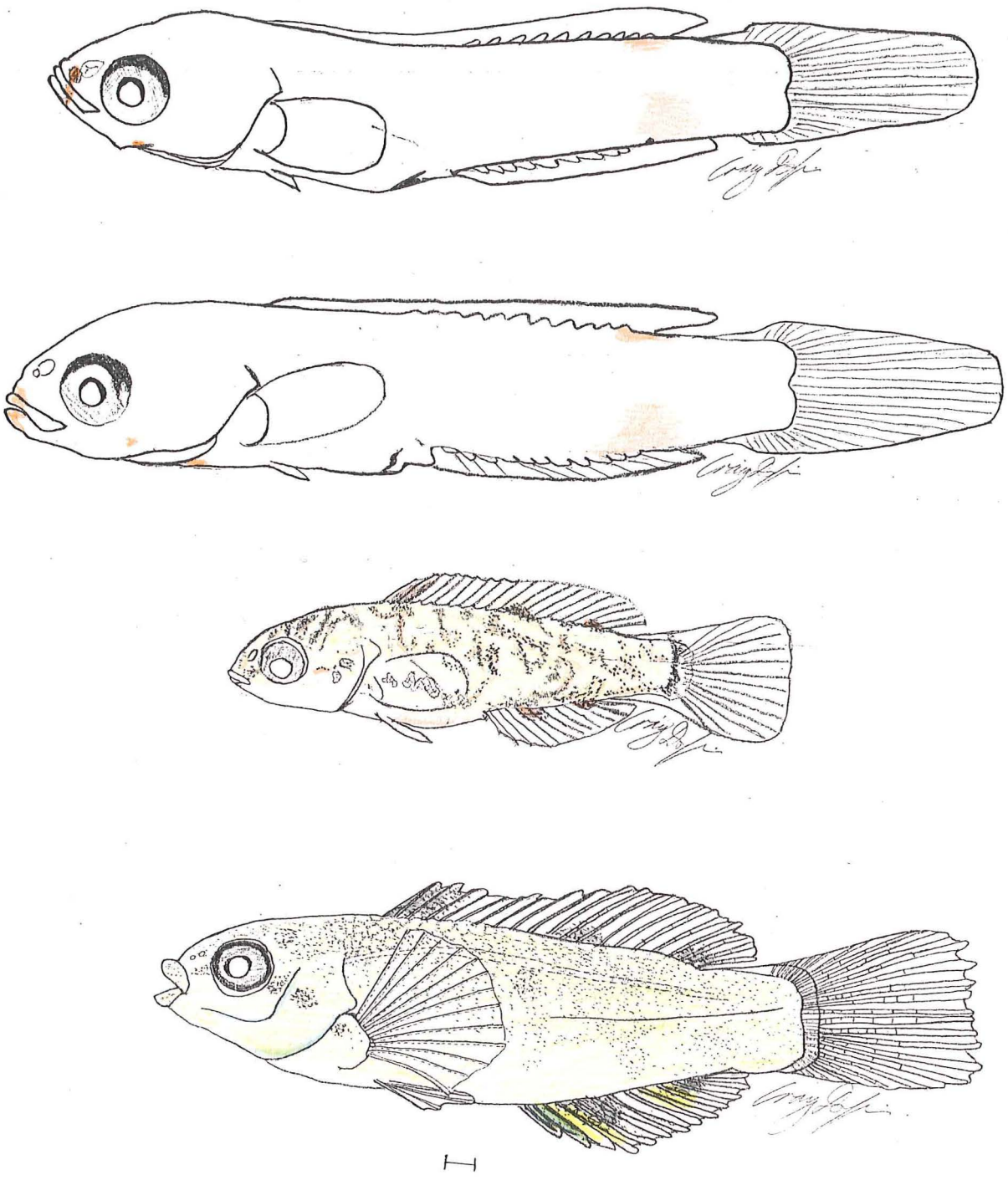

Figure 2.26 Partial development of the spotty (*Notolabrus celidotus*)
(scale = 1 mm)
a) 12 mm TL
b) 14 mm TL
c) 16 mm TL
d) 27.8 mm TL

Family Odacidae

Odax pullus (Bloch & Schneider) **Butterfish**

Eggs of butterfish were described by Ritchie (1969) and Robertson (1973, 1975) as spherical with a diameter between 1.975 and 2.125 mm and having no oil droplets. Robertson (1975) found them to be "occasional in central and southern New Zealand neritic waters in spring and summer." Crossland (1982) collected butterfish eggs in northland waters during October and December. Hatching occurs between 5 and 7 days after fertilisation (Ritchie, 1969).

Yolk-sac larvae were photographed by Ritchie (1969) and an illustration made from one of these photographs appears in Kingsford & Barrington (1986). Length at hatching is c. 4 mm from the scale given alongside Ritchie's photograph of a yolk-sac larva (1969, Fig.32).

As for Ritchie (1969) no butterfish larvae were captured in planktonic samples during this study. All specimens in this study were collected as eggs during daylight plankton tows, 1m below the surface, from October to January of 1995/96 and 1996/97. The eggs were within the dimensions given by Robertson (1975), and were faintly orange or pink in colour.

The youngest eggs collected were at the two-cell stage (Ritchie, 1969: Plate 18, Fig.1) which equates to 2 hours after fertilisation. Eggs were illustrated from approximately 12 hours after spawning to immediately prior to hatching (Fig. 2.27 a - h). Time to hatching is estimated to be 188 hours at 13°C. This is longer than that given by Ritchie (1969). This is probably the result of lower water temperatures.

Length at hatching was found to range from 5.8 to 6.0 mm TLL which suggests that the scale for Ritchie's (1969) photographs of yolk-sac larvae is misleading. Pigmentation is identical (Fig. 2.28 a) to that described by Ritchie with the base colouration of the body being green, and many small melanophores scattered across the body and head. The finfold is undifferentiated and originates above the brain. The anus is at c. mid-body. The eyes are poorly pigmented at hatching, but darken during yolk-sac absorption. The pectoral fins are present but small and barely visible.

The yolk sac is mostly absorbed after two days (Fig. 2.28 b) by which time the larvae are 7.6 mm TLL. The eyes and pectoral fins are more obvious and pigmentation is present on dorsal and anal finfolds around the caudal peduncle. This pigmentation pattern resembles an arrowhead pointing posteriorly at this stage.

This stage is equivalent to the illustration (Kingsford & Barrington, 1986) of the photographed specimen in Ritchie (1969). It is evident that the artist has confused the posterior margin of finfold pigment, with the posterior margin of the finfold itself. Examination of the photographs in Ritchie (1969) showed that the caudal part of the finfold is not visible.

At 9 days after hatching (Fig. 2.28 c) the pigmentation on the finfold has increased and is extending forward to the anus. Ossification of the caudal fin has begun. This larva died presumably because of starvation. The overall length is smaller (6.1 mm TL) as a result of this, in combination with shrinkage caused by death.

The longest-lived larvae in the laboratory was approximately 2 weeks old when it died. Behavioural observations of feeding were the same as Ritchie (1969). Larvae fed on rotifers and did best with only a very gentle water current. It is possible that the cause of death was starvation once rotifers became too small for the growing larva. Brine shrimp nauplii were available to the larvae, but they showed no interest in them. The dead larva was consumed by scavenging protozoans before it was discovered.

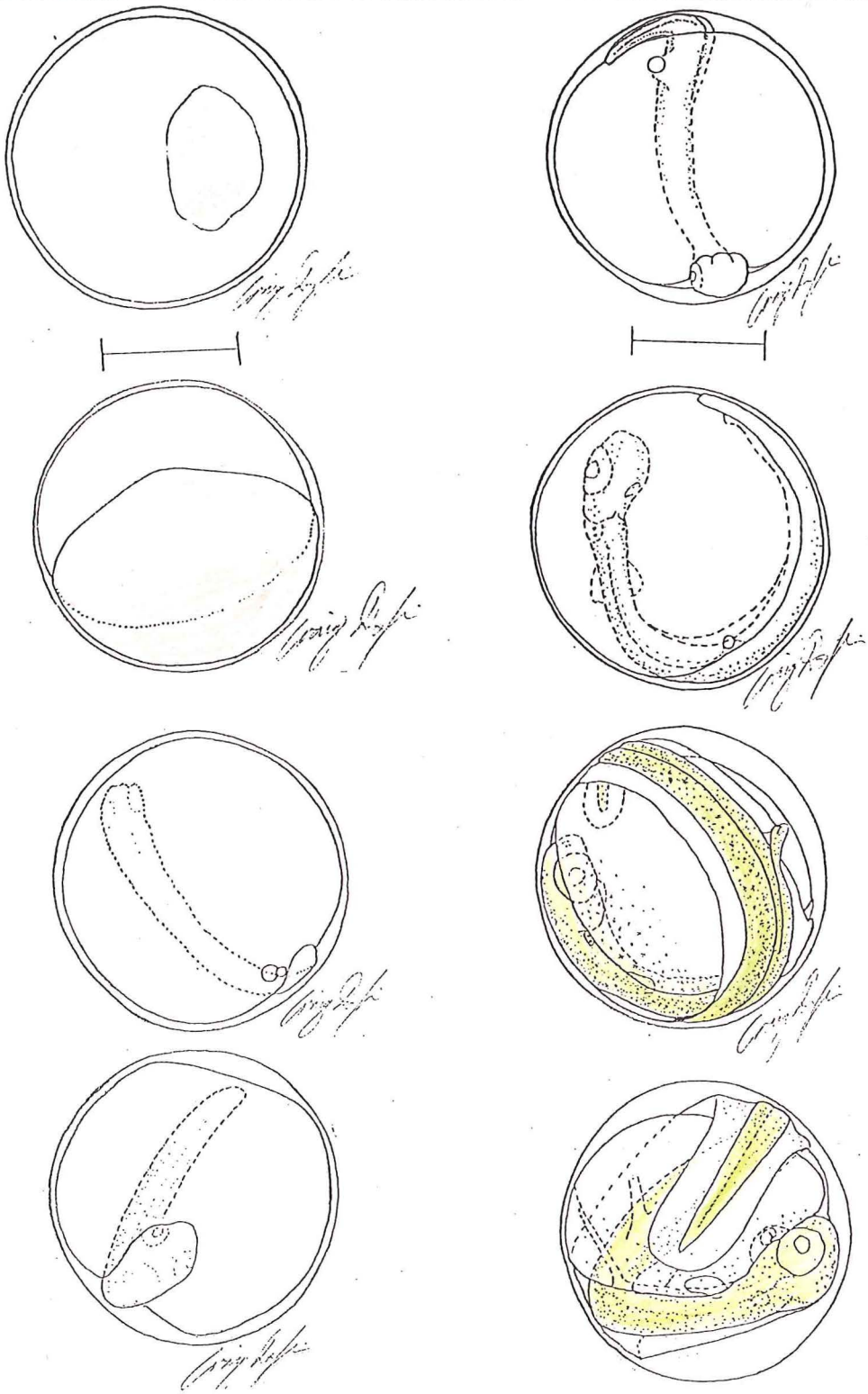

Figure 2.27 Egg development of butterfish (*Odax pullus*)

(scale = 1 mm)

a) 12 hours

b) 43 hours

c) 73 hours

d) 98 hours

e) 120 hours

f) 144 hours

g) 167 hours

h) 188 hours

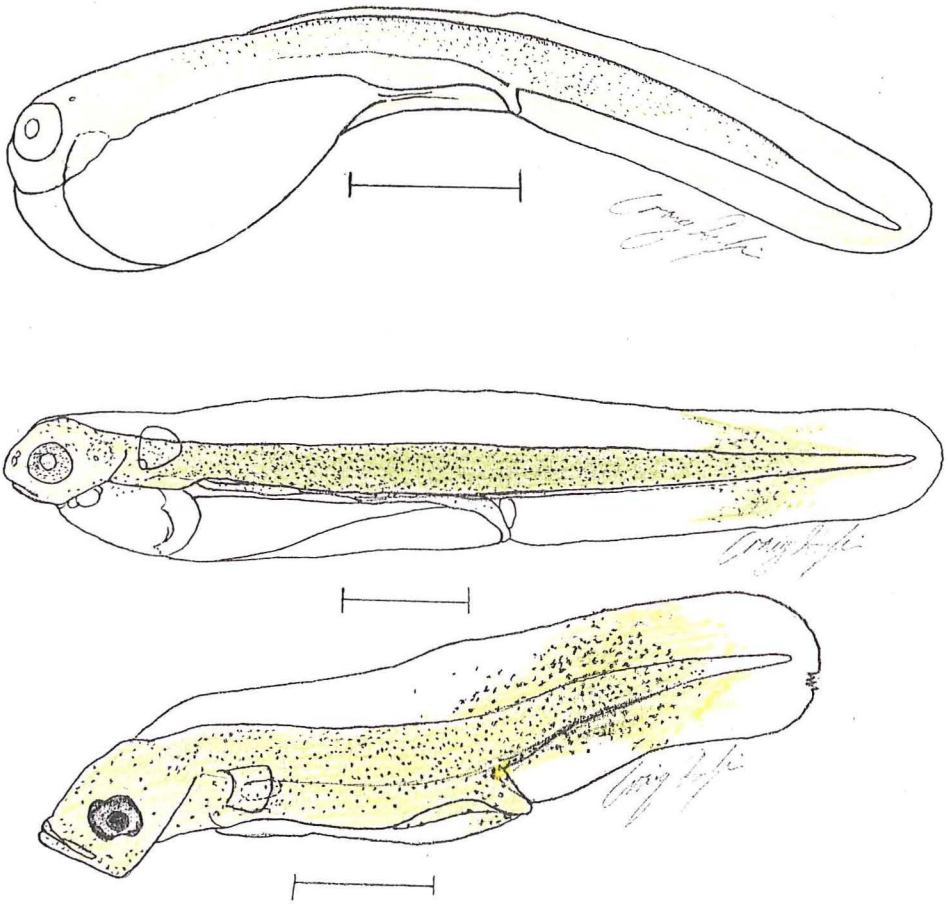

Figure 2.28 Early larval development of butterfish (*Odax pullus*)

(scale = 1 mm)

a) hatching (6.0 mm TL)

b) 2 days (7.6 mm TL)

c) 9 days (6.1 mm TL)

Family Bovichthyidae

Bovichtus variegatus (Richardson) **Thornfish**

Eggs of thornfishes are unknown and the only available illustration is of a pre-juvenile specimen 25.3 mm TL (Robertson & Mito, 1979). Strangely for a shallow-water coastal species, pelagic young of thornfishes are the most abundant species in plankton samples taken above the Campbell Plateau during summer (December to February) (Robertson & Mito, 1979). The authors comment that the low availability of suitable settlement habitat to the east and south of New Zealand may mean that most of these pelagic young will perish.

Most specimens in this study were collected in surface plankton tows at the 6 km site, in late July 1996. These were dead upon removal from the net in most instances. The few which were collected alive did not survive longer than one night in the laboratory even when larvae seemed healthy and active. It is supposed that these larvae were too stressed by capture and captivity to be viable. The only exception to this was the largest specimen collected (23.3 mm TL) which was kept alive for several days.

Only the largest specimen could be positively identified as *B. variegatus*. This was much larger than the smaller larvae attributed here to *B. variegatus* and the identification of smaller larvae should be treated as tentative. Identification was based on colouration, position of the anus, position of pelvic fins, timing of capture (i.e., allowing for growth between capture dates), and in the shape of the dorsal fin in the largest of the small larvae. Also, these larvae are very similar to illustrations of larvae, identified as thornfish, in a separate study on larval fish in Otago (M. Parsons, University of Otago, pers. comm.).

The smallest larva captured (Fig. 2.29 a) was 5.9 mm TL and is pre-flexion. The specimen is already heavily pigmented and has a silver appearance with blue/grey colouration dorsally. The finfold is non-differentiated and originates above the pectoral fin insertion dorsally and extends forward to the anus ventrally. The jaws are well formed. The gut is present and the anus is located immediately anterior to mid-body. There is no pigmentation on the caudal peduncle, or on the ventral surface of gut.

At 6.8 mm TL there has been little development apart from the body becoming slightly more robust in form (Fig. 2.29 b).

By 9.4 mm TL (Fig. 2.29 c) flexion has occurred and jugular pelvic fin buds are visible. The anterior part of the dorsal finfold is reduced in height to a point immediately anterior to the anus. Thereafter the finfold retains its original height. Constriction of the finfold around the caudal peduncle is also evident. Pigmentation is much the same as in earlier larvae with some melanophores now present on the caudal peduncle. There is no sign yet of the opercular spine which is prominent on juveniles and adults of this species.

A large pre-juvenile (Fig. 2.29 d) was captured in October 1996. This was characterised by silver colouration laterally and ventrally, and by blue/grey colour dorsally. The fins are all well formed with fully ossified fin rays. The large spine at the upper operculum edge is prominent at this stage. This spine first forms at c. 12 mm (M. Parsons, University of Otago, pers. comm).

Newly settled juveniles were captured in rock pools on Point Kean reef, Kaikoura, in August 1996. These were c. 35 mm - 40 mm TL at the time of capture. Colouration ranged from silver (ventrally and laterally, with red bars extending down from the dorsal surface), to the more cryptic mottled pattern associated with adult thornfish.

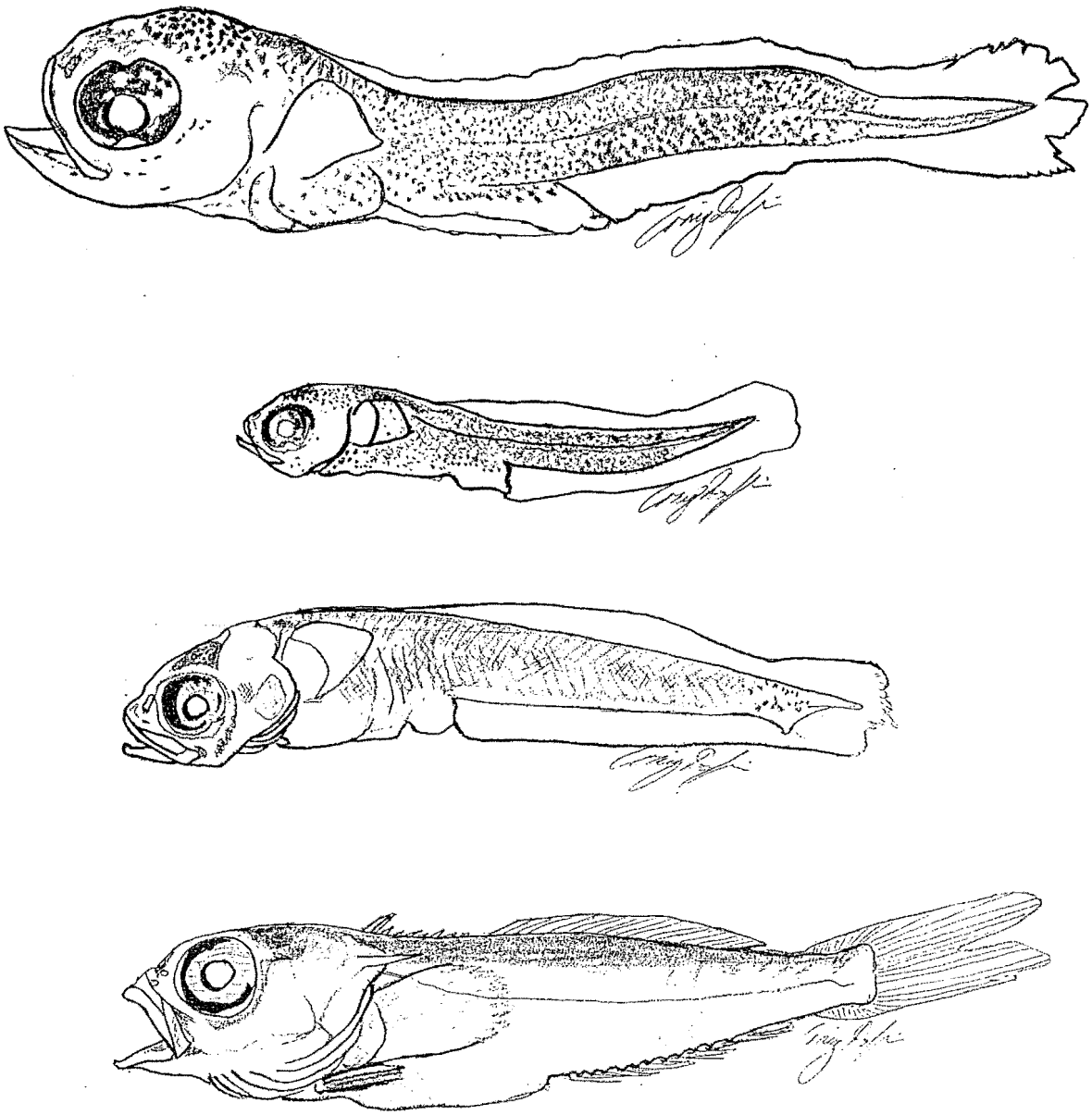

Figure 2.29 Development of thornfish (*Bovichtus variegatus*)

a) 5.9 mm TL

b) 6.8 mm TL

c) 9.4 mm TL

d) 23.3 mm TL

Family Uranoscopidae

Genyagnus monopterygius (Bloch & Schneider)

Spotted Stargazer

Eggs were described as being spherical with a diameter between 1.8 mm and 2.0 mm, possessing between 3 and 9 oil droplets (0.075 mm to 0.125 mm diameter) (Robertson, 1975). Crossland (1981) refined this by noting that the oil droplets coalesce during development to form larger oil droplets. Robertson (1975) stated that the eggs are common in Otago Harbour during summer while Crossland (1981) found these to be common in October and November, but rare from December onwards in the Hauraki Gulf.

A full developmental series of larvae is illustrated by Crossland (1981). These illustrations are not accompanied by a written description. The larvae were taken during October to January in the central Hauraki Gulf.

Specimens in this study were captured as both eggs and larvae. Three late stage eggs were captured in plankton tows 1m below the surface in late January 1997 (2 at the 2 km site, and one at the mouth of the Kowhai River). A total of four larvae and pre-juveniles were captured in the summer of 1995/1996 and 1996/1997. Two pre-juveniles were between 35 - 40 mm TL and were recognisable using adult characters. The larvae were both c. 13.5 mm TL. The first of these larvae was dead upon removal from the net, while the second was collected alive and kept for several days in captivity. During captivity the larva readily adapted to feeding on brine shrimp nauplii.

The eggs were kept alive and hatched on the same day as capture. Yolk-sac larvae are pale white in colour and have a large yolk. The finfold originates dorsally at the snout and the anus position is slightly forward of mid-body. One of these larvae died just after hatching and was consumed by scavenging protozoans.

After two days the yolk has been mostly absorbed (Fig. 2.30 a) and the mean length of the two larvae was 5.74 mm TLL. The eyes are well developed and darkly pigmented, with the anterior two-thirds of the body pigmented light green. Stellate melanophores are present along the ventral midline from beneath the posterior edge of the pectoral fins, and extending posteriorly to the

7th or 8h post-anal myotome. Stellate melanophores are also present around the remaining yolk, particularly at the anterior end, and also around the brain. A metallic-gold sheen can be seen on the upper operculum, and on the sides from the pectoral fin insertion to the anus. This is present in small patches along the notochord. There is the suggestion of constriction of the finfold around the caudal peduncle but this is not very obvious. The jaws are present but poorly formed. One larva died during measurement.

Three days after hatching (Fig. 2.30 b) yolk-sac absorption is complete. The larva has fully functional jaws with a single large tooth on each side of the ventral jaw. The maxilla extends approximately to mid-way below the eye, and the single nasal aperture is beginning to divide in two. Body depth has increased and the gut is well formed, but the total length has decreased slightly.

The metallic-gold colour (cross-hatching) has extended to cover a much larger area, but green-brown pigment can still be seen forward of the anus. Dark pigmentation is prominent at the anterior end of the gut and along the ventral midline from above the gut to just posterior to the anus.

Five days after hatching, the larva was feeding heavily on rotifers and was very active in the aquarium. Total live length had increased to 5.8 mm (Fig. 2.30 c), and the golden colour had extended to cover the entire front-half of the body. White pigmentation has become visible in the sub-dermal space at the base of the dorsal finfold in two places. One of these areas is immediately above the brain, and the other extends from above the mid-gut to above the anus. Several teeth are now present on both jaws. Unfortunately the larva did not recover from the anaesthetic after this illustration was made.

The live, wild-caught larva (Fig. 2.30 d) was 13.6 mm TL and golden-yellow in colour. Pigmentation is absent from the caudal peduncle. The maxilla extends beneath the eye. Flexion has occurred and fin rays are visible in dorsal, pectoral, anal, and caudal fins. The jugular pelvic fins are now present. Anterior to the origin of rays, the dorsal finfold is much reduced in height. The dorsal fin origin is slightly forward of the anus. The anus is now posterior to the mid-point of the body. Meristic counts are presented in Table 2.12. The chin barbel is not evident in either specimen of this size.

The shiny-golden colour of live individuals fades rapidly after death to a dull yellow colour and this loss of colour is exacerbated by preservation in formalin or alcohol.

Table 2.12 Meristic counts of spotted stargazer larvae and pre-juvenile.

Age	Total Length	Dorsal	Anal	Pectoral	Chin Barbel	Body Colour
hatching	?	-	-	-	-	pale white
2 days	5.7 mm	-	-	-	-	light green, with traces of gold
3 days	5.7 mm	-	-	-	-	gold colour increasing
5 days	5.8 mm	-	-	-	-	anterior half metallic-gold, posterior non-pigmented
?	13.6 mm	17	14	12	-	golden yellow, caudal peduncle non-pigmented
?	35 mm	17			yes	yellow, with 2 green stripes on each side

The later-stage pelagic juveniles are yellow with horizontal grey-green stripes on either side of the dorsal midline, and also dorso-laterally, along the length of the body. The chin barbel is present and these pre-juveniles can be identified using adult characteristics.

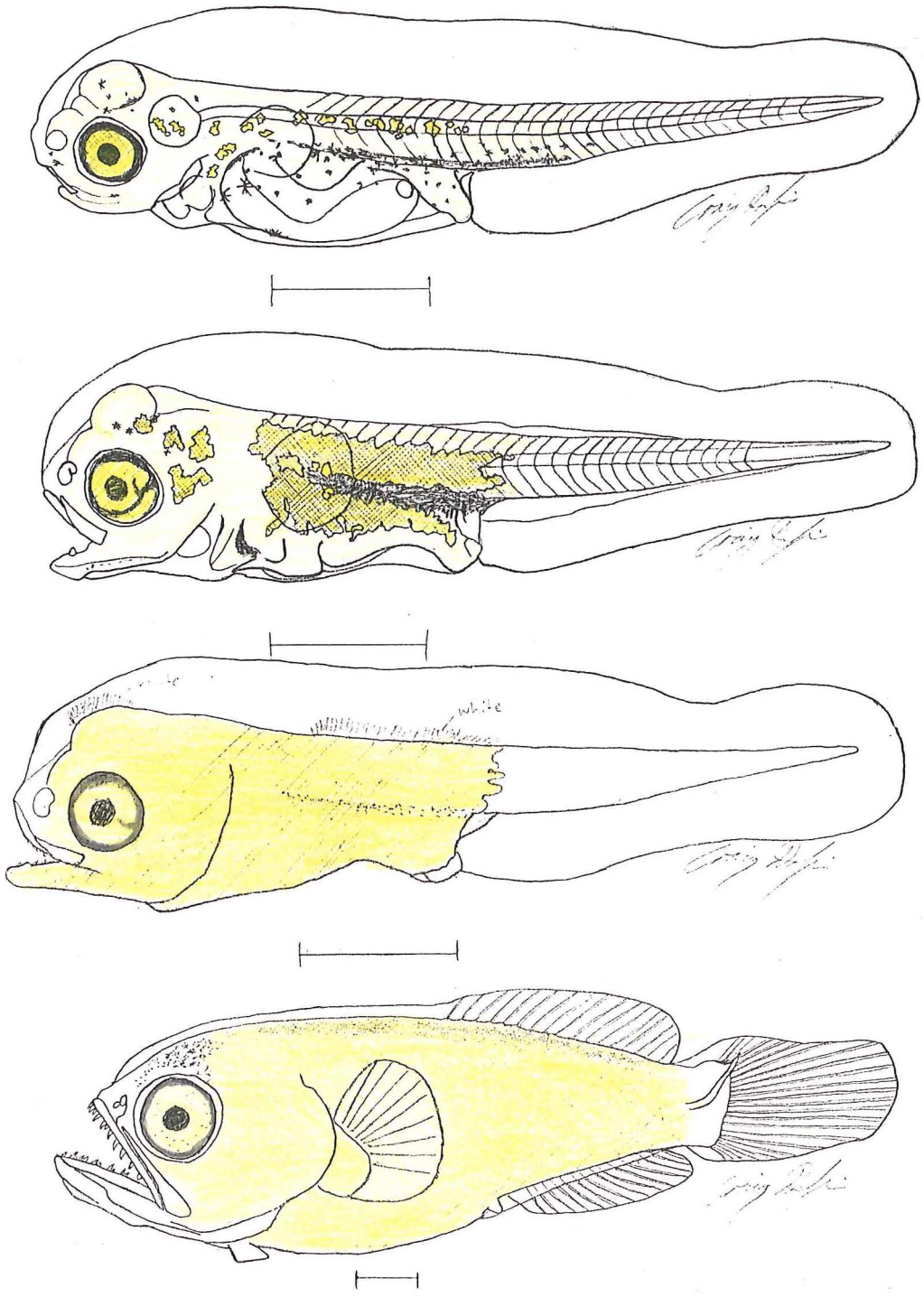

Figure 2.30 Development of the spotted stargazer (*Genyagnus monopterygius*)

(scale = 1 mm)

a) 5.7 mm (2 days)

b) 5.7 mm (3 days)

c) 5.8 mm (5 days)

d) 13.6 mm

Family Pinguipedidae

Parapercis colias (Bloch & Schneider) **Blue Cod**

Blue cod spawn during spring and summer (Graham, 1956; Robertson, 1973; Robertson, 1975). The eggs are between 1.10 and 1.25 mm diameter, and have a single oil droplet (0.225 - 0.300 mm diameter) and a non-segmented yolk (Anderton, 1910; Thomson and Anderton, 1921; Robertson, 1975).

Anderton (1910) illustrates the development of the egg, and larvae up to 15 days old, but fails to provide a scale for illustrated specimens (reproduced in Thomson & Anderton, 1921). Robertson (1973, pg 344) illustrates a late stage embryo, and a yolk-sac larva of 3.1 mm TL. Rapson (1956) contains photographs of two larvae (size unknown) identified as blue cod. However, Elder (1966) considers these larvae to be those of rockfish (*A. fuscus*).

Yolk-sac larvae have poorly pigmented eyes, but the eyes darken as the yolk is absorbed. The oil droplet is positioned posteriorly, and stellate pigmentation is present on it. Other pigmentation consists of two lateral rows of melanophores behind the head, and a band of black pigment between the anus and tail. Yellow pigment is also present on the finfold behind the head, slightly behind the anus, and halfway between the anus and the tail (Anderton, 1910). The yellow pigmentation is not visible in Robertson's (1973) illustration, but this could be due to preservation in formalin prior to drawing.

At 15 days old the larvae appear to be losing the pigment band between the anus and tail (Anderton, 1910). Also, the beginning of ossification in the caudal fin rays is visible, although the finfold has not begun to constrict. The yellow pigmentation on the dorsal finfold behind the head, and above the anus, is now more extensive.

Two specimens were captured in this study (Ref. Collection. CR). These were both caught in a surface plankton tow on April 21, 1995, approximately 100m offshore from New Brighton beach, Christchurch. These were identified from the largest of the larvae using adult characters in Paulin *et al.* (1989).

The smallest of the larvae is 13.7 mm TL (Fig. 2.31 a) and is post-flexion. All fins are present. Spines and rays are visible, but meristic counts are lower in this larva than in the larger specimen (Table 2.13).

Seven prominent spines are present at the posterior edge of the pre-operculum. Teeth are present on both jaws, and the maxilla is already beginning to be occluded by the preorbital. The anterior nostril has a short tube surrounding it. The two rows of melanophores behind the head illustrated by Robertson (1973) are still evident in this larva. They arise at the nape and extend to the origin of the soft dorsal fin rays. Stellate melanophores are present above the midbrain and on the operculum and preoperculum, as well as across the gut. Fin pigmentation is restricted to some small stellate melanophores between the rays of the pelvic fins, a small patch of melanophores at the base of the anal fin (at approximately one quarter of the anal fin length), and a prominent group of melanophores on the lower pectoral fin. This last seems to be a characteristic feature of the species and may be useful for identifying larvae of this species. No other pigmentation is present on the body above the gut.

Table 2.13 Meristic counts from two blue cod larvae.

Total Length	Dorsal	Anal	Pelvic	Preopercular Spines
13.7 mm	II, 19	I, 13	I,5	7
23.6 mm	IV, 21	I, 14	I,5	4

At 23.6 mm TL (Fig. 2.31 b) the larva is more elongate in form, and is heavily pigmented. The shape of the head is taking on the characteristic shape of blue cod, and the preorbital is covering more of the maxilla. The preopercular spines are fewer (Table 2.13) and less prominent. There is a shallow depression along the dorsal midline from the back of the head to the dorsal fin origin. Pigmentation is more widespread on the body and fins. The dorsal and anal fins are extensively pigmented brown, except for the posterior margins. The pelvic fins are more heavily pigmented, and the distinctive pigmentation on the pectoral fins is still prominent. There are four vertical bars of fine punctate melanophores on the body, separated by vertical bars of stellate melanophores. These stellate melanophores are largest on the sides and are reduced dorsally. The posterior part of the caudal peduncle, and the caudal fin, are non-pigmented.

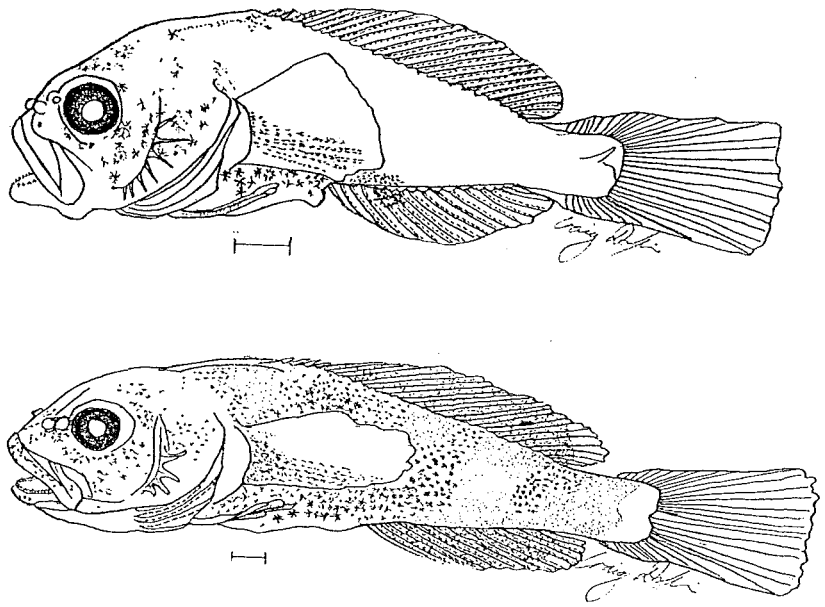

Figure 2.31 Larva and pre-juvenile blue cod (*Parapercis colias*)

(scale = 1 mm)

a) 13.7 mm TL

b) 23.6 mm TL

Family Tripterygiidae

The family tripterygiidae is commonly represented in the intertidal and sublittoral fauna around the New Zealand coastline. There is much confusion in the taxonomy of this group with only the recent work of Hardy (1987, 1989a, 1989b) and Fricke & Roberts (1993) attempting to untangle the nomenclature. The situation is even more confused with respect to larval tripterygiids. Some studies have not attempted to identify triplefins to generic level. Crossland (1981, 1982) grouped triplefin larvae as tripterygiidae. Robertson (1973) either did not capture triplefin larvae in his plankton samples, or alternatively, did not include them in his unpublished thesis results. Kingsford (1986) separated the genera *Forsterygion* and *Gilloblennius*, and Roper (1981, 1986) identified *Gilloblennius decemdigitatus*, but did not separate the other tripterygiids, from larvae caught in the outflow of Whangateau Harbour. Elder (1966) identified two species of triplefin and grouped the remainder as '*Tripterygium* sp'. He also mistakenly placed another tripterygiid, *G. decemdigitatus*, within the family Eleotridae. Frentzos (1980) shows photographs of several species of triplefin but also includes unknown 'tripterygiid larvae'. Several species have been fully described as larvae by Ruck (1973b, 1976, 1980). Scientific names in this study are assigned in line with Hardy's (1987, 1989a, 1989b) findings. However, several species remain undescribed and, even among those which are described, identification remains difficult.

Larval triplefins share common characteristics and are easy to separate from other families of larval fishes. All triplefin larvae have their anus positioned at approximately one third of their total length. The eye is usually well pigmented and has a silvery lateral surface. There are usually two large melanophores present on the dorsal surface of the gut peritoneum. One is immediately anterior to the anus, and the other is above the pyloric region of the gut. Also, there is usually a series of melanophores present along the post-anal ventral contour.

Pelvic fin formation usually occurs late in development. Most yolk-sac larvae have a prominent green gall bladder present and few differences can be detected between species at this stage of development. Characters used by Ruck (1973b, 1980) to contrast several species, such as length at hatching and

the number of ventral melanophores, are highly variable even within a single cluster of eggs and are unlikely to be useful in identifying triplefin larvae in plankton samples. An important character for species identification may be the patterns of pigmentation present dorsally above the head. However, these may not be useful until larvae are larger than 10 mm.

There appear to be two groups within the family. Ruck (1980) found differences between the egg structures laid by *Gilloblennius* and *Forsterygion*, and also the yolk-sac larvae of these genera (however, the species he identified as *G. decemdigitatus* is properly assigned to the genus *Ruanoho)*. It seems that the pattern of dorsal fin formation is different in *Gilloblennius tripennis* and *Notoclinus* than in *Grahamina*, *Ruanoho*, or *Forsterygion*. In *Gilloblennius* and *Notoclinus*, the original finfold gives rise to all three of the dorsal fin structures found in adults. By contrast, in *Grahamina, Ruanoho,* and *Forsterygion*, the original finfold only gives rise to the third dorsal fin of the adult (the first and second dorsal fins arise separately after the third has formed).

Ruck (1980) also mentioned that species of *Forsterygion* and *Ruanoho* lay their eggs in a single sheet. *Grahamina* species also lay eggs in a single layer, while *Gilloblennius* lays eggs in multiple layers. It is currently unknown how *Notoclinus* lay their eggs.

It is suggested here that the pattern of dorsal fin development, and possibly egg laying patterns, separate the genera *Gilloblennius* and *Notoclinus* from *Grahamina*, *Ruanoho*, and *Forsterygion*. *Ruanoho decemdigitatus* may be more similar to *Gilloblennius* and *Notoclinus* than *Forsterygion* and *Grahamina* species, based on the existence of a large melanophore above the brain in yolk-sac larvae.

Family Tripterygiidae

Forsterygion lapillum (Hardy) **Common Triplefin**

Eggs of this species have been fully described and illustrated under the name *Tripterygium capito* (Ruck, 1973b). These are demersal and are cared for by the male parent. Development of the embryo until hatching takes c. 17 days in

temperatures ranging from 11.5 - 13.5 °C. Upon hatching, the yolk-sac larvae have a mean total length of 5.17 mm.

Illustrations of the larval stages of this species are less accessible with only the yolk-sac larvae illustrated and published (Ruck, 1973a). Later stage larvae of this species are presently unknown.

Specimens in this study were collected from October to March in plankton tows at all sites. These were among the most abundant larval fish encountered, and were present at the surface, 1m, and 3 m below the surface. However, they were only recognisable above 10.5 mm TL and no difference could be seen between smaller tripterygiid larvae of this genus, or *Grahamina* larvae. Pre-juveniles were captured in great abundances with light traps in shallow water (<4 m) on the inside of Baxter's reef in January, 1997. These were relatively non-pigmented, but began to develop juvenile colouration within a few days of capture. Juveniles of this species have a distinctive longitudinal stripe dorso-laterally.

At 10.5 mm (Fig. 2.32 a) flexion has already occurred and the finfold is constricted around the caudal peduncle, separating the caudal fin from the remainder of the finfold. The anterior part of the dorsal finfold is reduced in height. Fin ray formation is not yet evident. Pigmentation above the head consists of a single black melanophore above the myelencephalon and two yellow chromatophores at the rear of each of the midbrain lobes.

At 16 mm TL (Fig. 2.32 b) the dorsal finfold has become restricted to the region of the adult's third dorsal fin and fin rays are visible within it. The anal fin rays are also present (Table 2.14). Pigmentation on the head is the same as earlier but with two small black melanophores present above the middle of each lobe of the midbrain, anterior to the two yellow chromatophores. Also, a melanophore is evident at the base of the pectoral fin which is present in most larvae from this size upwards.

Two melanophore bars appear at the base of the caudal fin rays by c. 18 mm TL. Pelvic fins appear at 15 mm TL (Fig. 2.32 c) and the second dorsal fin is present by c. 21 mm TL (Fig. 2.32 d) with the first dorsal fin arising soon thereafter (c. 25 mm).

Table 2.14 Meristic counts of *Forsterygion lapillum*.

Total Length	First Dorsal	Second Dorsal	Third Dorsal	Anal
10.5 mm	-	-.	-	-
15.5 mm	-	-	12	26
21.0 mm	-	XX	12	27
24.5 mm	*	XX	12	27
29 mm	VI	XX	12	28
Adult**	VI	XX	12	26

* present but spines not visible
** from Ayling & Cox, 1987

Settlement is likely to occur after a size of approximately 27 mm, since pre-juveniles were still pelagic at this size. Observation of wild larvae, whilst snorkelling in South Bay during December and January, suggests that triplefin larvae form large monospecific schools of two or three hundred individuals. All individuals in these schools have very similar patterns of pigmentation above the brain. These may range from sizes as large as 30 mm TL, to as small as c. 7 TL. These schools are unlikely to be from individual egg clusters since larvae hatch out over a period of several days and currents would disperse the larvae.

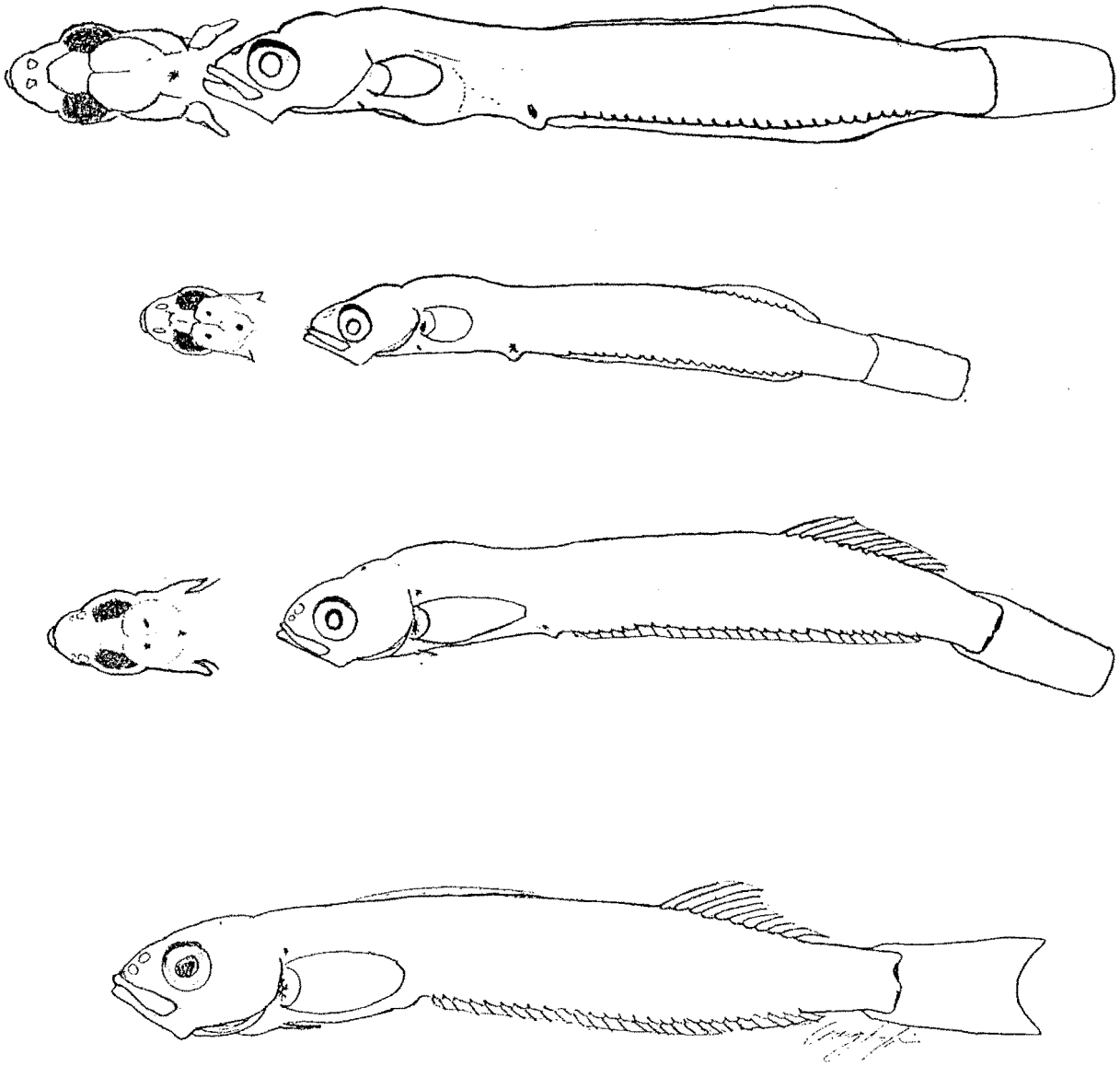

Figure 2.32 Partial development of *Forsterygion lapillum*

a) 11.5 mm TL

b) 16 mm TL

c) 20 mm TL

d) 24 mm TL

Family Tripterygiidae

Grahamina capito (Fricke & Roberts) **Spotted Robust Triplefin**

Nothing is presently known about the early life history of this species. Larvae in this study were collected by a hand-held plankton net while snorkelling in shallow water on the inside of Baxter's Reef, during December and January 1995/1996. They were taken back to the laboratory and reared on a diet of mosquito larvae and brine shrimp nauplii.

The smallest larva collected was 8 mm TL (Fig. 2.33 a) and was very similar to most triplefin larvae. Flexion had occurred but was incomplete. Distinctive characters are pigmentation on the head and at the base of the caudal fin rays. The crown of the head has a single black melanophore along the dorsal midline above the midbrain. Also, yellow pigmentation is present around the midbrain but is concentrated anteriorly and posteriorly. A series of contracted melanophores is present extending along the post-anal ventral midline to the caudal peduncle. A vertical pigment bar is present along the bases of the ventral caudal rays. The caudal rays have begun to ossify and the finfold is constricting around the caudal peduncle.

The pelvic fin buds appear first in larvae which are 10 mm TL (Fig. 2.33 b). Flexion is complete by this length. Pigmentation on the head is unchanged, but the two melanophores on the dorsal surface of the gut have merged and form a large pigment block. More contracted melanophores are present along the ventral midline. The pigment bar along the bases of the caudal rays now has a dorsal counterpart. The caudal fin is fully ossified and separate from the dorsal and anal finfolds. The anterior part of the dorsal finfold is reduced in height.

At 12 mm TL the yellow pigmentation around the midbrain extends to include the forebrain. The anterior part of the dorsal finfold has disappeared and the remainder has rays visible within it. The dorsal fin is the adult's third-dorsal fin. Anal fin rays are also visible (Table 2.15).

The yellow pigmentation around the midbrain and forebrain is most pronounced at a size of approximately 15 mm TL. At this stage the central melanophore above the midbrain may have divided into two or more

melanophores. Small contracted melanophores have appeared at the bases of the dorsal fin rays.

Table 2.15 Meristic counts of *Grahamina capito* during development.

Total Length	First Dorsal	Second dorsal	Third Dorsal	Anal	Pelvic
8 mm	-	-	-	-	-
10 mm	-	-	-	-	1
12 mm	-	-	12	21	1
15 mm	-	-	12	21	1
18 mm	-	developing	12	21	1
22 mm	IV	XVI	12	21	2
60 mm	VI	XX	15	26	2
Adult*	V-VIII	XVII-XXIII	10-16	22-31	2

* from Fricke & Roberts, 1993

At 18 mm TL (Fig. 2.33 c) the yellow pigmentation is beginning to reduce around the brain. The pelvic fins are beginning to extend noticeably but still have only one ray each, and the adult's second-dorsal fin has begun to arise in front of the original dorsal fin. A small orange chromatophore is present in front of the pelvic fin insertion, on the ventral midline of the cleithral symphysis. Pigmentation at the bases of the third-dorsal fin rays is more pronounced.

At 21 mm TL (Fig. 2.33 d) the first-dorsal fin has appeared and the second-dorsal fin has increased in height. All traces of the yellow pigmentation around the brain have vanished but groups of punctate melanophores are present dorsally above the midbrain and dorso-laterally behind the eyes. Further punctate pigmentation can be seen on the operculum and in scattered patches across the body. The supra-orbital tentacle has 3 branches.

At 22 mm TL (Fig. 2.33 e) the captive larvae had developed cryptic pigmentation on the body, and also the pectoral and dorsal fins. The dorsal fins are well developed and comparable to illustrations of adult *G. capito* (Fricke & Roberts, 1993). This pigmentation increases as the juveniles continue to grow. However, meristic counts of these juveniles were lower than those for adults (Table 2.15).

One larva was ongrown to a length of approximately 60 mm TL. At this size the first dorsal fin count was within the meristic range given by Fricke & Roberts (1993). This suggests that triplefins do not finish fin ray formation until late in their juvenile development.

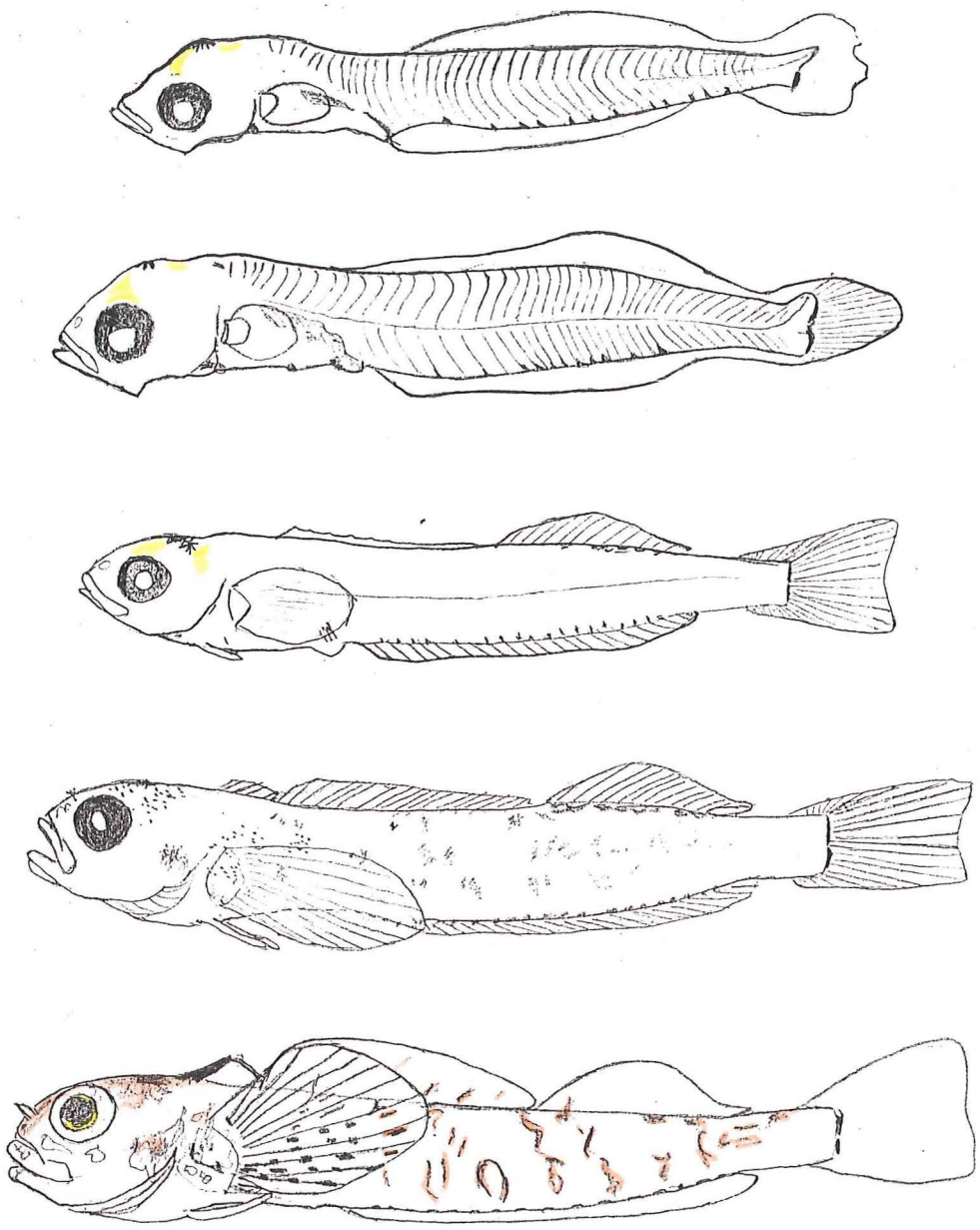

Figure 2.33 Development of *Grahamina capito*

a) 8 mm TL

b) 10 mm TL

c) 18 mm TL

d) 21 mm TL

e) 22 mm TL

Family Tripterygiidae

Grahamina signata (Fricke & Roberts)

Multi-tentacled Robust Triplefin

Nothing is presently known about the early life history of this species. Specimens in this study were collected as egg clusters found attached underneath intertidal rubble. These clusters were collected from immediately in front of the Edward Percival Field Station between late August and November, 1996. All egg clusters were attended by an adult *Grahamina signata* which was collected to confirm species identification. Adults were identified using an unpublished key to the triplefins (Stewart, 1995). However, it should be noted that almost all adults collected had supraorbital tentacles with 5 branches instead of the 6-10 stated by Fricke & Roberts (1993). The only australasian tripterygiid with this number of supraorbital branches is the Tasmanian robust triplefin (*G. gymnota*) which is unknown in New Zealand.

Egg clusters of this species are generally salmon-pink in appearance due to the colouration of multiple oil droplets within the yolk. Eggs (Fig. 2.34 a, b) are laid in a single layer and have a mean diameter of 1.13 mm (1.08 - 1.23 mm; s = 0.04; n = 10). These are attached to the substrate by fine elastic filaments which project from the chorion. These filaments also tangle with filaments from nearby eggs. As with other triplefin egg clusters (Ruck, 1980) it is evident that there are distinct areas within the cluster at differing stages of development. This is evidence for serial spawning. Multiple yellow chromatophores are present across the body and yolk of the developing embryos. The oil droplets coalesce during development becoming fewer and larger as the embryo approaches hatching. The time to hatching was not measured because eggs were collected from the wild and often these were well developed prior to collection.

Yolk-sac larvae range from 6.1 mm - 6.4 mm TLL (Fig. 2.34 c). These are essentially identical to other tripterygiid yolk-sac larvae (e.g., Ruck, 1980), with two melanophores on the dorsal surface of the gut peritoneum and a series of contracted melanophores on the ventral midline. Seventeen yolk-sac larvae from the same egg cluster had a range of 1 - 12 (mean 8.2) of these ventral

melanophores at hatching. By the time the yolk had been absorbed (Fig. 2.34 d) there were between 6 and 17 of these (mean 10.2; n=11). In life the green gall bladder was highly visible during this stage and some yellow chromatophores were present half-way between the anus and the tip of the notochord along the dorsal midline (usually 2 - 3) and ventral midline (usually 1 - 2).

Attempts to rear yolk-sac larvae were unsuccessful even though larvae were seen to feed actively on rotifers. The largest larvae reared grew to 7.7 mm TL (Fig. 2.34 e). At this size the gut is well formed and the melanophores on the dorsal surface of the gut peritoneum have increased in number and size. A single stellate melanophore is present on the cleithral symphysis, and another is visible on the dorsal surface of the myelencephalon. Caudal fin rays are beginning to ossify and the origin of the dorsal finfold is beginning to retreat posteriorly. The number of contracted melanophores in this specimen was 17.

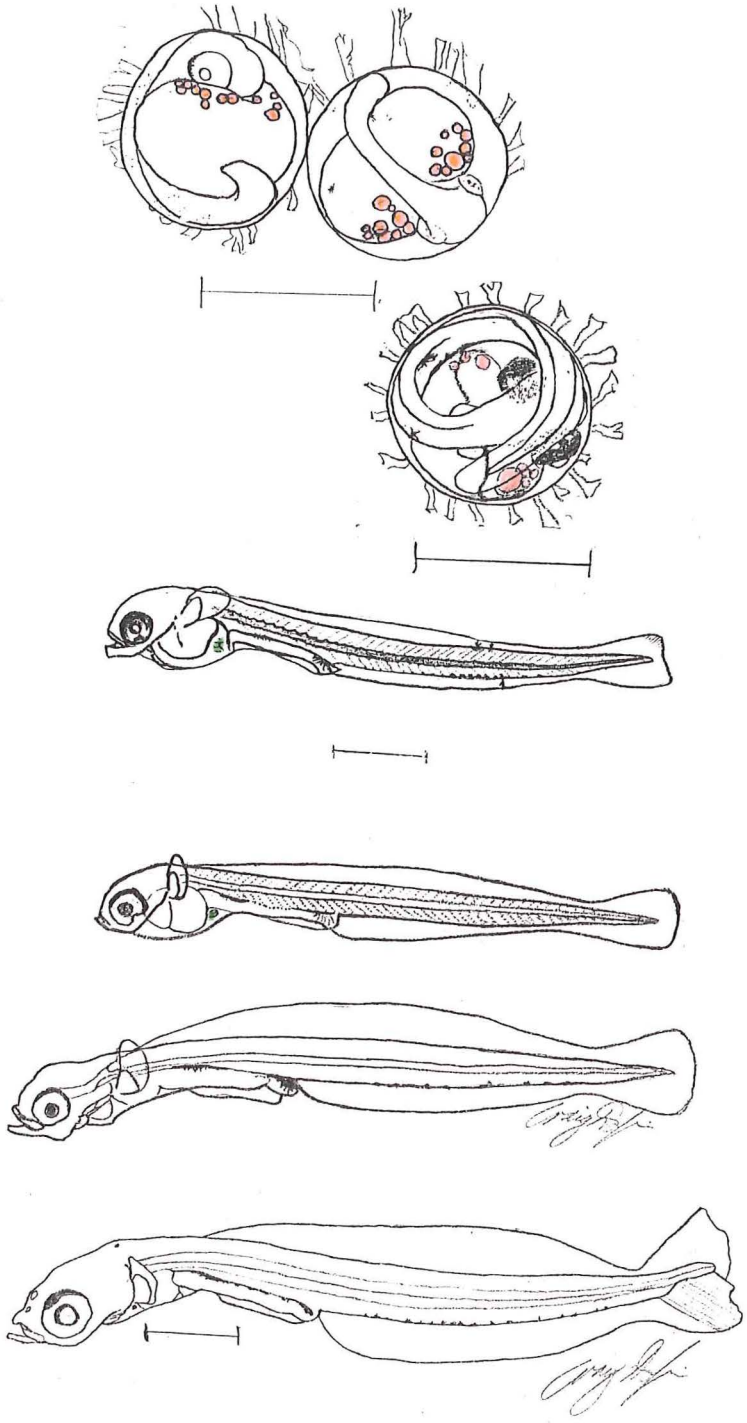

Figure 2.34 Early development of *Grahamina signata*

(scale = 1 mm)

a) Eggs (3 days before hatching)

b) Egg (on day of hatching)

c) Yolk-sac Larva 6.38 mm TLL

d) Larva 7.25 mm TL

e) Larva 7.7 mm TL

Family Tripterygiidae

Gilloblennius tripennis (Bloch & Schneider) **Thripenny**

Gilloblennius tripennis has been described and illustrated as eggs and yolk-sac larvae by Ruck (1980). The eggs are spherical with a diameter between 1.32 and 1.40 mm. These are usually laid down in several layers, and are attached to each other by tendrils which arise from over the entire chorion. The egg mass is anchored to the rock by the tendrils of the layer closest to the substrate. Yolk-sac larvae have a mean total length of 5.93 mm upon hatching. Later stage larvae are illustrated in Ruck (1976).

Specimens in this study (Ref. Collection AI) were caught infrequently in surface plankton tows during summer months, to as late as mid-April. Identification was achieved by rearing one viable larva from c. 12 mm TL to a size of 18 mm TL. This was confirmed by comparison of wild-caught larvae to illustrations in Ruck (1976, 1980).

The smallest specimen captured was 7.4 mm TL (Fig. 2.35 a) and is preflexion. The dorsal midline above the mesencephalon is dominated by a single, large stellate melanophore. Similarly, the dorsal surface of the gut peritoneum is characterised by two large stellate melanophores. These melanophores are much larger than their counterparts in triplefin larvae of the genera *Grahamina* or *Forsterygion*. Several small stellate melanophores are scattered across the yolk-sac. Some very small contracted melanophores are present on the caudal peduncle but the heavy pigmentation around the notochord tip shown in Ruck (1976) is absent in all individuals captured. Contracted melanophores are present in a series along the ventral midline.

Flexion occurs, and the pelvic fin buds arise, by the time a larva reaches 9.3 mm (Ruck, 1976: Fig 7.2b).

At 11.4 mm TL (Fig. 2.35 b) the dorsal and anal finfolds are separated from the caudal fin, and fin rays can be seen. All three dorsal fins are visible at this stage but are not yet very high. Pigmentation is virtually unchanged although the melanophores across the gut are more numerous. Pelvic fins remain small.

By 18 mm TL (Fig. 2.35 c) the dorsal fins are approaching the same relative height observed in adults. Meristic counts are given in Table 2.16.

Pigmentation is more prominent across the gut and head. The stellate melanophores are accompanied by brown pigmentation, which is also present on the first dorsal fin and on the operculum behind the eye. Punctate pigmentation is present above the midbrain, on the operculum and below the eye.

Table 2.16 Meristic counts of *Gilloblennius tripennis* during development.

Total Length	First Dorsal	Second Dorsal	Third Dorsal	Anal	Pelvic
7.4 mm	-	-	-	-	-
9.3 mm*	-	-	-	-	1
11.4 mm	†	XV	13	24	1
18.0 mm	III	XV	13	II, 24	2
Adult	III	XVII	13	II, 24	2

† too small to see spines
* from Ruck (1976)

Larvae of this species can be distinguished from larvae of the similar species *Notoclinus compressus* by the presence of numerous melanophores scattered across the gut surface. Also, the large stellate melanophores on the dorsal surface of the gut peritoneum are smaller in *G. tripennis* than in *N. compressus*. *G. tripennis* larvae do not have large stellate melanophores on the anterior part of the gut, while there are at least two of these present in *N. compressus* larvae. Late stage larvae and pre-juveniles of these two species differ markedly in pigmentation patterns. In particular, *G. tripennis* do not have the crimson-red colouration along the vertebral column or alternating pigmented and transparent sections of the dorsal and anal fins.

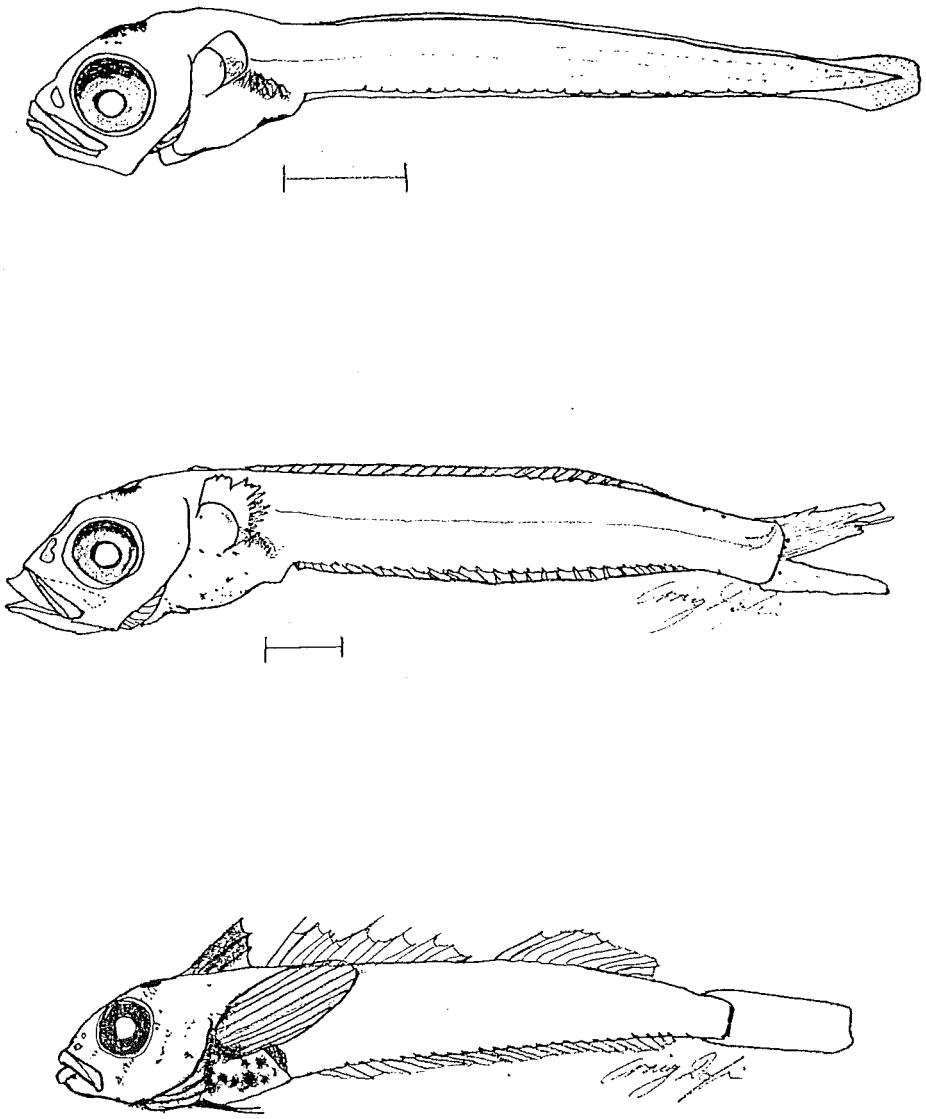

Figure 2.35 Development of thripenny (*Gilloblennius tripennis*)

(scale = 1 mm)

a) 7.4 mm TL

b) 11.4 mm TL

c) 18.0 mm TL

Family Tripterygiidae

Notoclinus fenestratus (Bloch & Schneider) **Topknot**

Eggs of this species are presently undescribed, but (Ruck, 1976) illustrated a 9.8 mm TL larva.

Specimens in this study (Ref. Collection W) were captured during plankton tows during January and February of 1996 and 1997. Larvae were collected infrequently by daylight surface plankton tows at South Bay. Most larvae were dead upon removal from the net, except for two that were kept alive from a length of approximately 12 mm TL, to 16 mm and 20.4 mm TL respectively, on a diet of brine shrimp.

The smallest larva was 12.2 mm TL (Fig. 2.36 a) and differs from Ruck's illustration (1976: Fig. 15.3) of a 9.8 mm TL larva by the finfold which is now differentiated into dorsal, anal, and caudal fins. The dorsal finfold is not yet separated into three fins, although some poorly developed fin rays are visible within it. Anal and caudal fin rays are present. The pelvic fins are present and longer than for a similar stage *G. tripennis* larva.

Pigmentation around the gut is particularly heavy, and the dorsal surface above the midbrain is dominated by a very large stellate melanophore. One - two small melanophores are also present on the operculum behind the eye. A stellate melanophore can be seen at the bases of the pelvic fins. Two melanophores are present at the base of the caudal rays. The number of contracted melanophores along the ventral midline is variable, but generally higher than *G. tripennis*.

By 14.2 mm TL (Fig. 2.36 b) all three dorsal fins are well developed and fin rays are present. Pigmentation on the head is heavier with the small melanophores behind the eye becoming larger and more numerous. Also, stellate melanophores are present on the pectoral fin bases. Meristic counts are presented in Table 2.17.

At 16 mm TL (Fig. 2.36 c) pigmentation overall has increased markedly. Head pigmentation is dominated by a series of brown pigment bands and patches, which extend through, and onto, the eye itself. The first dorsal fin, and sections of fin membrane of the second and third dorsal fins are pigmented brown. These pigmented sections alternate with completely transparent

sections and effectively break up the outline of the fish. This pattern is also present on the anal fin. Additionally, crimson-red colouration is visible at the nape behind the head and running along the dorsal aspect of the vertebral column. Meristic counts are presented in Table 2.17.

Table 2.17 Meristic counts of *Notoclinus fenestratus*.

	First Dorsal	Second Dorsal	Third Dorsal	Anal
12.2 mm	-	-	-	19
14.2 mm	IV	XII	9	19
16.0 mm	IV	XII	11	21
20.4 mm	IV	XII	11	21
Adult*	IV	XI	13	24
N. compressus †	IV	X	10	19

* from a Ayling & Cox, 1987
† from Stewart, 1995

At 20.4 mm TL (Fig. 2.36 d) the only significant difference was an increase in pigmentation. Crimson-red pigment has extended onto the pectoral, pelvic, and caudal fins. Pigmentation on the dorsal and anal fins also includes crimson-red pigmentation in the previously completely transparent sections. The bands of pigment on the head and eyes are more defined and extend onto the premaxilla and the lower jaw. Punctate pigmentation is present anterior to the orbit also.

Larvae of this species can be distinguished from larvae of the similar species *Gilloblennius tripennis* by the absence of numerous melanophores scattered across the gut surface. Also, the large stellate melanophores on the dorsal surface of the gut peritoneum are smaller in *G. tripennis* than in *N. fenestratus*. *N. fenestratus* have at least two large, stellate melanophores on the anterior part of the gut while *G. tripennis* larvae do not usually have these (they are much smaller if present). Late stage larvae and pre-juveniles of these two species differ markedly in pigmentation patterns. In particular, *G. tripennis* do not have the crimson-red colouration along the vertebral column or alternating pigmented and transparent sections of the dorsal and anal fins.

However, differences between *N. fenestratus* and *N. compressus* are less obvious. Both are highly similar during development (Ruck, 1976) although *N. compressus* has contracted melanophores at the base of the fin rays of the

third dorsal fin (Ruck, 1976) and *N. fenestratus* does not (Ruck, 1976, Fig. 17.1; c.f. Fig. 2.36 a-d). Also, *N. fenestratus* has more fin rays in the anal and second and third dorsal fins (Table 2.17).

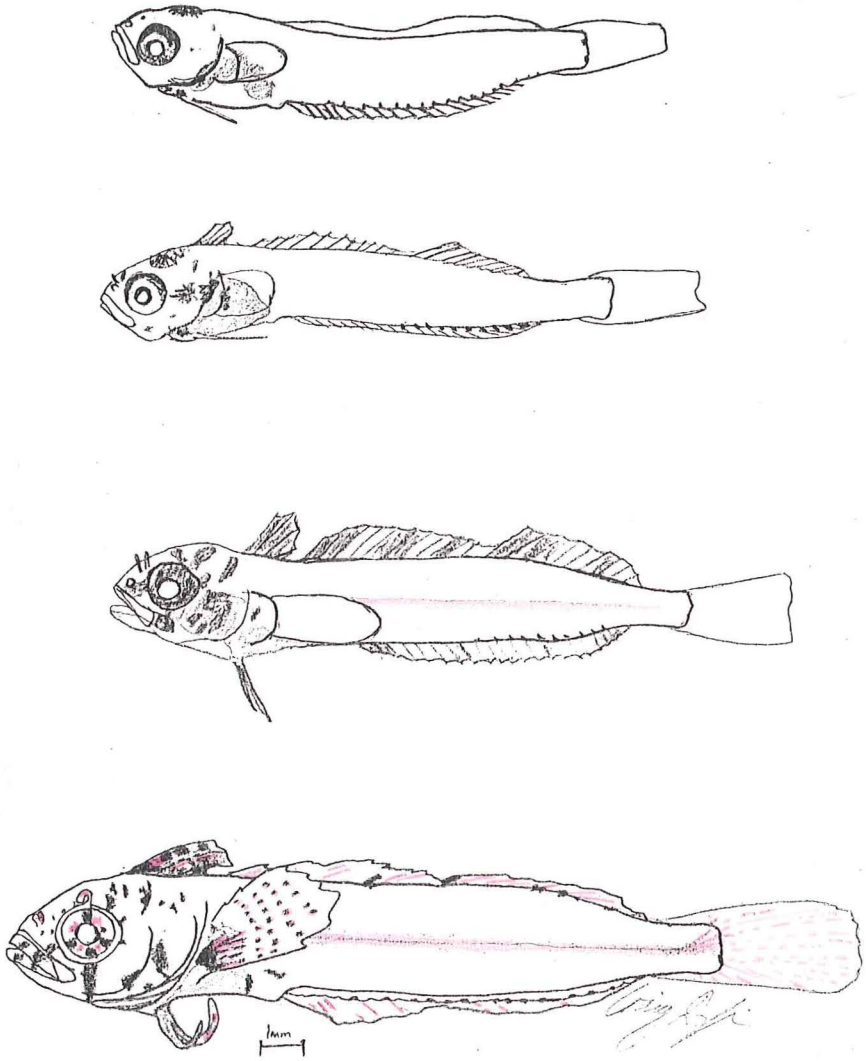

Figure2.36 Partial development of the topknot (*Notoclinus fenestratus*)

a) 12.2 mm TL

b) 14.2 mm TL

c) 16.0 mm TL

d) 20.4 mm TL

Family Tripterygiidae

Ruanoho decemdigitatus (Clarke) **Longfinned Triplefin**

Eggs and larvae of *R. decemdigitatus* have been fully described and illustrated by Ruck (1976, 1980). Illustrations from Ruck (1980) have been reproduced in Kingsford & Barrington (1986). Larvae have also been described and illustrated by Roper (1981). Elder (1966, Fig.6) identified *R. decemdigitatus* as an unknown species of the family Eleotridae.

The demersal eggs are laid under intertidal rubble, and attended by the male parent. They are spherical with a diameter of 1.12 - 1.20 mm, and have fine elastic tendrils arising from over the entire chorion. They are laid down in a single layer (Ruck, 1980).

Yolk-sac larvae have a mean length at hatching of 5.24 mm TL which increases to 5.8 mm TL after 5 days (Ruck, 1980). A large stellate melanophore appears above the midbrain at this stage. The larvae also have a highly distinctive pattern of melanophores along the dorsal and ventral midlines of the body. There are usually three large stellate melanophores along the dorsal midline, and three or four large stellate melanophores along the ventral midline opposite the dorsal melanophores. Small melanophores are present in the gaps between the large melanophores. In unpreserved specimens, yellow chromatophores can also be seen along the dorsal and ventral midline between the large melanophores. As with all other tripterygiids, two stellate melanophores are present on the dorsal surface of the gut peritoneum.

Specimens in this study (Ref. Collection R) were collected in daylight plankton tows from October through to February, at most sites sampled.

The smallest larva collected was 5.0 mm TL (Fig. 2.37 a). This had no melanophore above the midbrain but did have the distinctive melanophore pattern along the dorsal and ventral midlines.

By 6 mm TL (Fig. 3.37 b) the melanophore above the midbrain has appeared and is present in all stages after this. An additional melanophore appears near the base of the caudal rays and this persists throughout the pre-flexion and mid-flexion stages.

Flexion begins at approximately 7 mm TL (Fig. 2.37 c) and is not complete until 11 mm TL (Fig. 2.37 d). During this time, the distinctive pattern of

melanophores begins to become more variable with up to 5 or 6 melanophores being large and obvious along both dorsal and ventral midlines. The caudal fin does not separate from the rest of the finfold until approximately 11 mm TL. During flexion, the origin of the dorsal finfold begins to retreat from immediately behind the head.

At 13 mm TL (Fig. 2.37 e) the dorsal finfold has retreated to the position of the adult's third dorsal fin and fin rays have begun to ossify. The anal and caudal fins also have fin rays present (Table 2.18). The melanophore pattern is breaking down further at this stage, particularly along the ventral midline where several melanophores have appeared. The pelvic fins have remained relatively small up to this point but begin to lengthen as development continues. Ruck (1976: Fig. 8.3) shows that the second dorsal fin of the adult is present at this stage, but this was not visible in larvae collected in this study until much later.

Table 2.18 Meristic counts of *Ruanoho decemdigitatus*.

Total Length	First Dorsal	Second Dorsal	Third Dorsal	Anal
10.3 mm	-	-	-	-
13.0 mm	-	-	-	25
16.5 mm	-	XVI	11	25
25.1 mm	III	XVIII	13	25
Adult*	III	XIX	13	25

*from Ayling & Cox, 1987

By 17 mm TL (Fig. 2.37 f) the style of melanophore along the dorsal midline has changed. The single stellate melanophores have divided into two large melanophores on either side of the midline. Also, the number of these melanophore pairs is increasing. Similarly, lateral melanophores associated with the vertebrae in the caudal peduncle are beginning to appear. The second dorsal fin has begun to arise and fin rays are visible within it. The first dorsal fin is not yet present.

Pigmentation is essentially unchanged at 20 mm TL. Ruck (1976: Fig. 9) illustrates a 25.7 mm TL larva that has all three dorsal fins present and large, well developed pelvic fins. Pigmentation along the dorsal midline has increased and punctate melanophores are present on the head. Small, stellate melanophores are also present on the mouth and below the cleithral

symphysis. The lateral melanophores associated with the vertebrae have extended forwards, and contracted melanophores are present at the base of the anal fin rays.

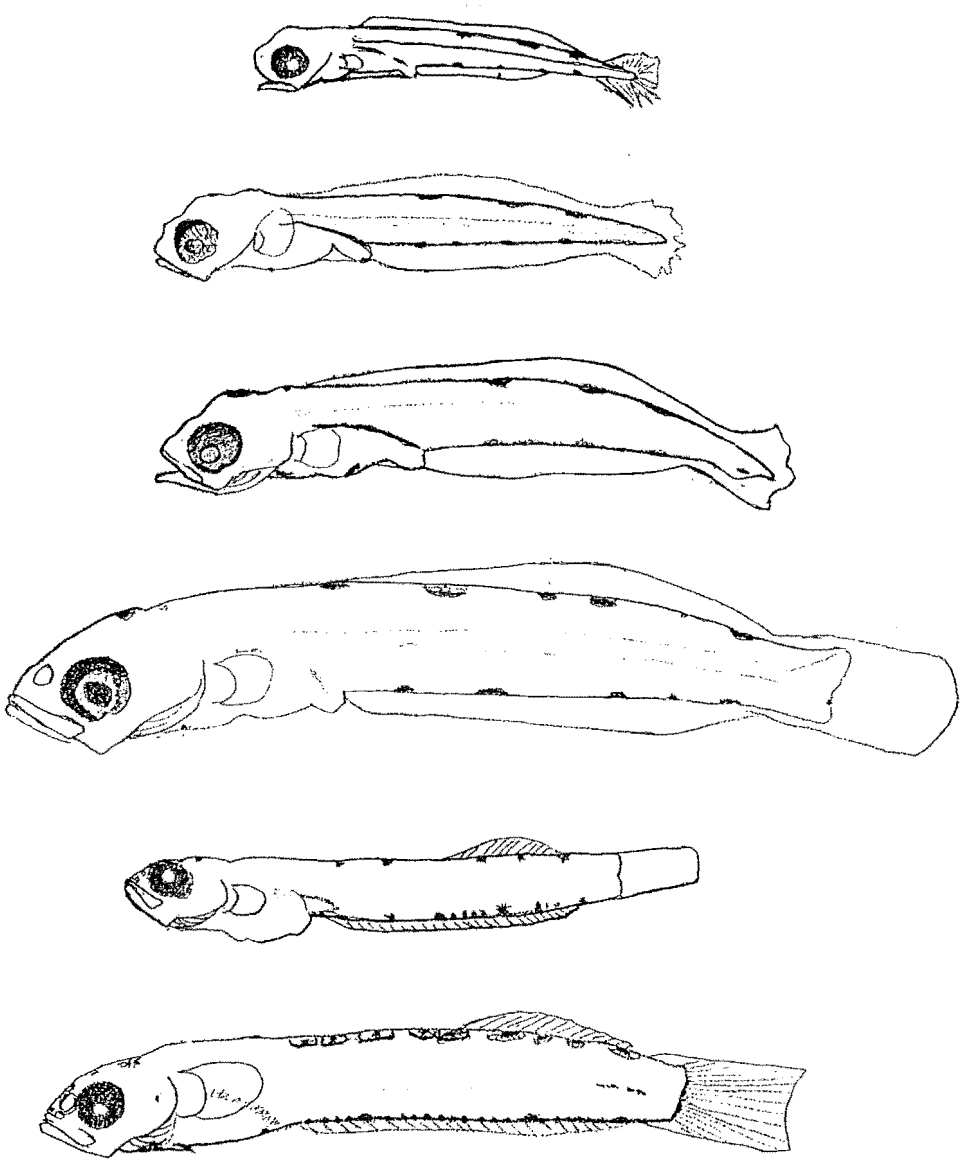

Figure 2.37 Development of *Ruanoho decemdigitatus*

a) 5.0 mm TL

b) 6.0 mm TL

c) 7.0 mm TL

d) 11.0 mm TL

e) 13.0 mm TL

f) 17.0 mm TL

Family Eleotrididae

Grahamichthys radiata (Quoy & Gaimard, in Cuvier and Valenciennes) **Graham's Gudgeon**

Graham's gudgeon is a common species present in shallow coastal waters around much of New Zealand. Robertson (1973) considered that spawning occurred throughout the year. Eggs have not been described or illustrated, but larvae have been comprehensively described and illustrated by Elder (1966). Crossland (1981) also illustrated larvae, and Frentzos (1980) has photographs of a full developmental series. Elder (1966) suggested that larvae of this species are not common at depths which he sampled at (not given) and were likely to be found either at the surface or near the bottom. Robertson (1973) found larvae of this species mainly in night-time tows, with few larvae near the surface but at high abundances at depths of 8 - 10m below the surface. These larvae were confined to a 2 km strip of neritic water (Robertson, 1973).

No larvae were collected during any plankton tows during this study. However, a gravid female was collected in December, 1996, in the sea water intake filter at the Edward Percival Field Station. Given that spawning was imminent at the time of death it is highly probable that these larvae are present around the Kaikoura area.

Specimens for this study were hatched out from demersal eggs spawned in captivity at Otago University. The larvae are small at hatching (3.02 mm TLL; n = 1; Fig. 2.38 a) and have a highly prominent swimbladder. The yolk-sac is small. The black melanophores, which are so evident in later stage larvae, are not yet present. Yellow pigment is visible on the ventral midline immediately above the anus and also at a position approximately half-way between the anus and the tip of the notochord. The yellow pigment in this second area is stellate and extends up to the dorsal midline.

After 3 days the larvae have completely absorbed the yolk and are approximately 3.4 mm TLL (Fig. 2.38 b). The swimbladder is slightly more compressed dorso-ventrally and is covered on the dorsal surface by black pigmentation and is metallic-silver underneath. Melanophores are present along the ventral midline from behind the swimbladder to the second post-anal

myotome. A prominent stellate melanophore is present on the ventral midline half-way between the anus and the tip of the notochord. It extends up the sides almost to the dorsal midline and anteriorly and posteriorly so that it is present along a total of 6 myotomes. In between the fine branches of this melanophore the equally fine branches of the yellow stellate chromatophore can be seen in live specimens. This yellow pigment fades rapidly upon preservation. Yellow pigment above the anus is now completely obscured by black pigment.

No larvae lived longer than three days despite frequent but small (<5%), water changes and an abundance of rotifers and brine shrimp nauplii.

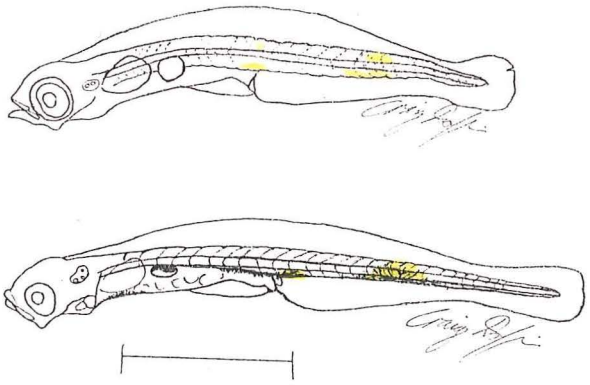

Figure 2.38 Early development of Graham's gudgeon (*Grahamichthys radiata*)
(scale = 1 mm)
a) 3.02 mm TL
b) 3.42 mm TL

Family Gobiidae

Gobiopsis atrata (Griffin) **Black Goby**

No gobies have been positively identified and described as eggs or larvae to species level in New Zealand. Roper (1981, reproduced in Kingsford & Barrington, 1986) illustrated one gobiid species, and described another. It is likely that one of those species is *Gobius lentiginosus*. The general description of gobiid larvae is very similar to the eleotrid *Grahamichthys radiatus*, with a prominent swimbladder. However, fin formation occurs at a smaller size (Roper, 1981). Late stage larvae have the fused pelvic fins that are characteristic of this family.

Only two specimens were collected in this study (Ref. Collection CC). These were collected at night at the end of January 1997 in a 1m deep plankton tow near a shingle beach in South Bay. These were both active and viable upon removal from the net. Late stage larvae of this species proved to be very durable. One of these was killed and preserved in 95% ethanol while the other was reared for a period of one month on a diet of brine shrimp nauplii. This larva was then killed and stored in 95 % ethanol.

The smallest of the larvae measured 11.62 mm TL (Fig. 2.39 a) and had well formed fins with rays visible. Meristic counts from this specimen are (D_1) V, (D_2) I,10, and (A) I,10. The pelvic fins are large and fused (12 fin rays, combined count). Pigmentation of the body is heavy. The larvae appear dark grey with a fawn strip running along the dorsal midline. Large stellate melanophores are present on the operculum behind the eye and on the head. More are present on the side of the body near the vertebral column. Punctate melanophores are present below the stellate melanophores, from the gut back to the caudal peduncle. Dorso-laterally from the snout to the caudal peduncle there are patchy areas of yellow pigmentation. Some traces of green pigment are visible on the operculum and pectoral fin base. Small spines are present along the lower edge of the jaw and operculum. These spines are not evident in Roper's (1981) illustrations. The swimbladder is not prominent at this stage of development, but early stage larvae of this species are likely to have a prominent swimbladder if development is similar between gobiid species.

The pattern of pigmentation and the presence of spines on the head in these specimens suggest that the larvae illustrated and described by Roper (1981) are not the same as those collected in this study.

The live larva grew to a size of 16.8 mm TL (Fig. 2.39 b) after a month in captivity and is juvenile. The overall colouration is black laterally and ventrally with a lighter shade of grey on the head and dorsally along the body. Lateral-line scales have become prominent, and pigmentation extends onto the caudal fin. More spines are present on the head below the eye and on the edge of the pre-operculum. Also, another series of spines is present behind the eye on the operculum.

This is the first record of a gobiid fish in Kaikoura.

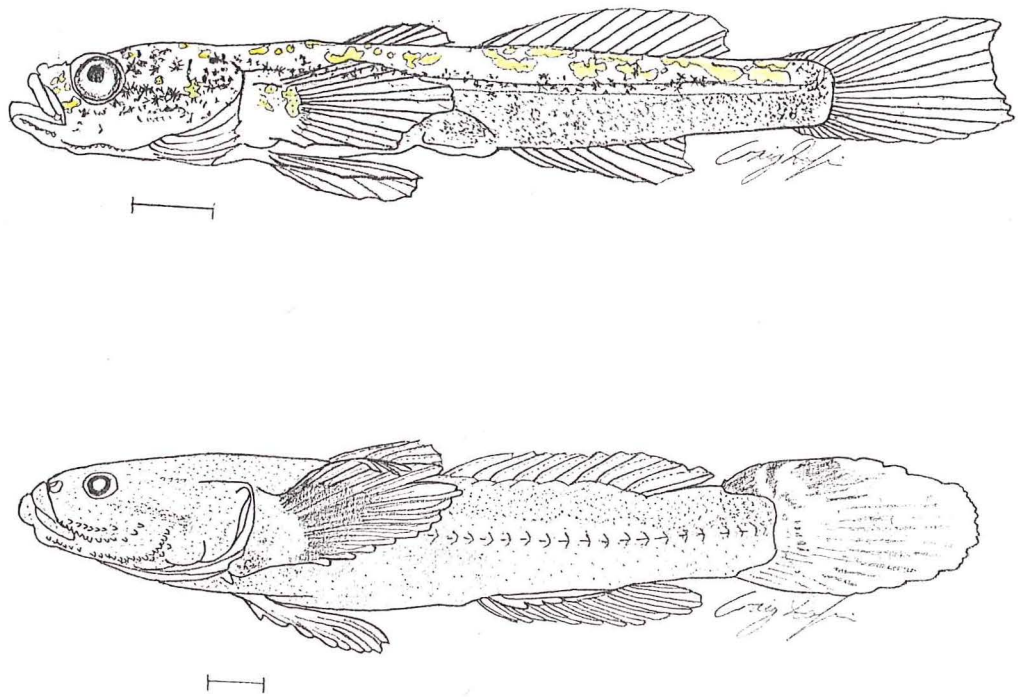

Figure 2.39 Late-larva and juvenile black goby (*Gobiopsis atrata*)

(scale = 1 mm)

a) 11.62 mm TL

b) 16.80 mm TL

Family Gempylidae

Thyrsites atun (Euphrasen) **Barracouta, Snoek**

Barracouta spawn from spring to autumn with peaks of spawning in October and November (Mehl, 1971). There is at least one major spawning ground centred above the Mernoo Bank on the Chatham Rise (Robertson & Mito, 1979). The eggs are between 0.91 and 1.06 mm in diameter with a single oil droplet (diameter 0.243 - 0.274 mm) (Robertson, 1975).

Larval barracouta have been illustrated in New Zealand by Robertson & Mito (1979) and Crossland (1982). Haigh (1972) features a full developmental series of barracouta larvae taken in South Africa. Illustrations by Robertson & Mito (1979) and Crossland (1982) agree closely with those in Haigh (1972).

Specimens in this study (Ref. Collection CL) were captured from February to April 1996 and 1997 in South Bay and the 2 km site. These were taken in daytime plankton tows at the surface or 1m below the surface. Larvae were drawn prior to preservation in 95% ethanol.

The smallest specimen captured was 9.2 mm SL (Fig. 2.40 a; Table 2.19) and flexion had already occurred. Haigh (1972) reports that flexion occurs at c. 7.5 mm SL. The dorsal fin spines are well developed and prominent. Three small spines are present on the posterior edge of the pre-operculum. The pelvic fins are distinctive with one very large spine that has serrated margins. A second non-serrated, smaller spine is also present.

Table 2.19 Meristic counts and measurements of *Thyrsites atun*.

Standard Length	Dorsal	Pelvic Spine Length/SL	Anus position (% SL)	HL/SL	BD/SL
9.2 mm	XIX,17	17%	60%	40%	28%
12.0 mm	XX,16	19%	68%	37%	26%
21.8 mm	XIX,19	13%	73%	34%	18%

The head is large and the maxilla extends to below the orbit. The anus is positioned behind mid-body. Punctate pigmentation is present above the midbrain and also in a line along either side of the dorsal midline. Several melanophores are present in a series along the lower jaw and also along the base of the anal fin. Some melanophores are also present on the posterior

vertebrae. Metallic-silver pigment is present on the sides behind the eye, and forward of the anus. This extends up to the dorsal midline and down to the gut.

At 12.0 mm SL (Fig. 2.40 b; Table 2.19) the larvae are slightly more elongate. Relative head length is reduced and the anus is positioned more posteriorly. Silver pigmentation has extended posteriorly as the anus has migrated backwards, but does not extend past the anus. The pelvic fin spine is relatively larger and now has 5 rays associated with it.

At 21.8 mm SL (Fig. 2.40 c; Table 2.19) the pre-juveniles are more elongate in form and the pelvic fin spine has begun to reduce. Head length has reduced relative to overall length. The anus has moved even further posteriorly. Silver pigmentation is present across most of the body except for the caudal peduncle.

From the illustrations and relative dimensions given in Haigh (1972) it would seem that larvae captured in this study are generally more stocky in shape (Table 2.20) and have a greater relative head length (Table 2.21). However, as the larvae approach juvenile size (>20 mm SL) they have more similar body dimensions. Body depth to standard length ratios (Table 2.20) taken from illustrations in Crossland (1982) and Robertson (1973) both compare more closely to values given in Haigh (1972) but are higher. Relative head length seems to be a more variable character and although these were higher in this study than in Haigh (1972), both Crossland (1982) and Robertson (1973) illustrate specimens with a much smaller relative head length. Specimens in this study were drawn prior to preservation in 95% ethanol and it is possible that differences in the state of preservation may explain the differences between specimens in this study and elsewhere.

Table 2.20 Relative body depth to standard length of *Thyrsites atun* larvae from four studies.

Standard Length	Haigh (1972)	This Study	Robertson (1973)	Crossland (1982)
c. 9 mm	21%	28%	n/a	24%
c. 12 mm	20%	26%	21%	n/a
c. 22 mm	16%	18%	n/a	n/a

Table 2.21 Relative head length to standard length of *Thyrsites atun* larvae from four studies.

Standard Length	Haigh (1972)	This Study	Robertson (1973)	Crossland (1982)
c. 9mm	38%	40%	n/a	31%
c. 12mm	36%	37%	34%	n/a
c. 22mm	31%	34%	n/a	n/a

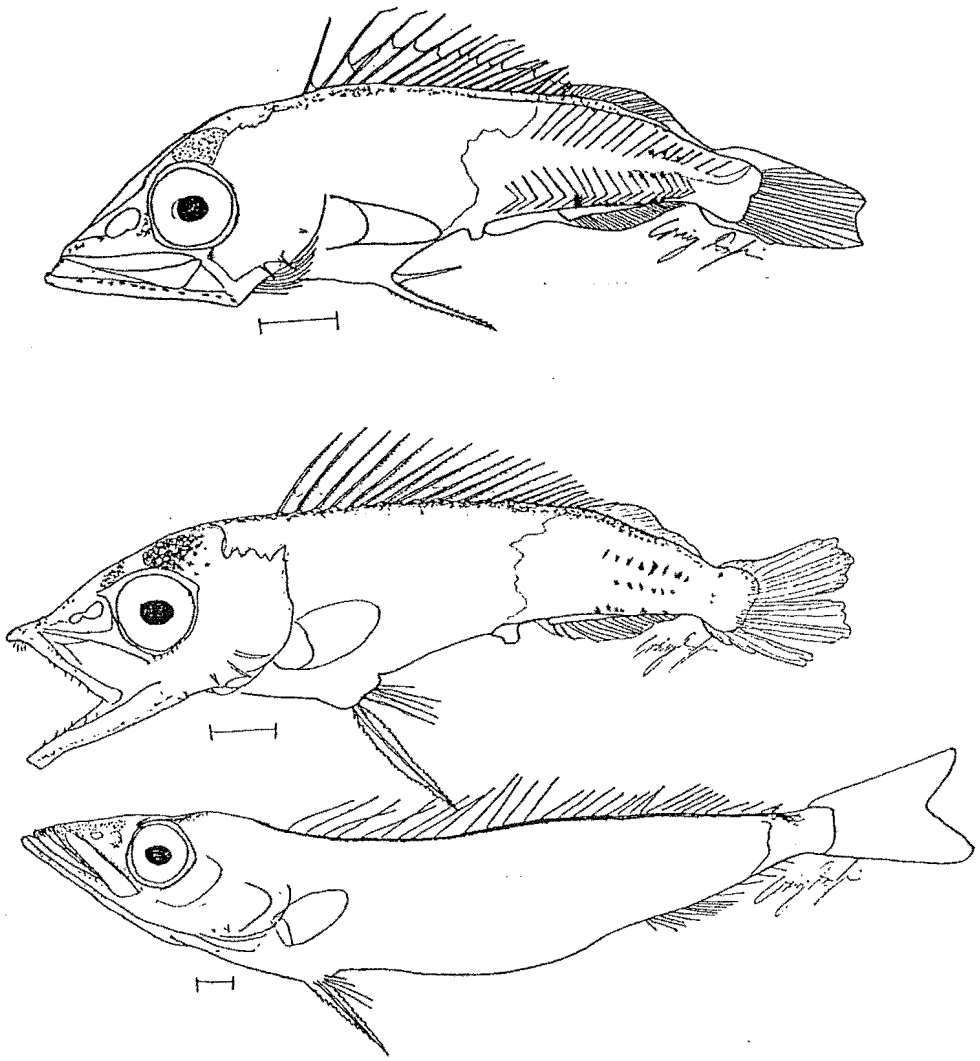

Figure 2.40 Partial development of barracouta (*Thyrsites atun*)

(scale = 1 mm)

a) 10.96 mm TL

b) 13.0 mm TL

c) 24.8 mm TL

Family Centrolophidae

Seriolella caerulea (Guichenot) **White Warehou**

White warehou are present in Tasmanian, New Zealand, and Patagonian (South America) waters. In New Zealand they are distributed mainly to the south and east of the South Island. Particularly large populations are present on the Mernoo Bank, Bounty Rise, and Campbell Plateau (McDowall, 1980).

Spawning in this species is known only from a single ripe, running female collected in late October, 1976. However, spawning in the closely related *Seriolella brama* is known to extend from spring to autumn, and there is no evidence to indicate that *S. caerulea* differs greatly from this.

McDowall (1980) reports that fertilised eggs of this species have a diameter between 1.98 and 2.07 mm (mean 2.03 mm) which have a single, golden-amber oil droplet with a diameter between 0.50 and 0.57 mm. The yolk is homogenous (non-segmented) and has a wide perivitelline space (0.15 mm on both sides). The eggs are larger than those of *S. brama* or *Seriolella punctata* which have a mean diameter of 1.47 mm and 1.14 mm respectively (Grimes & Robertson, 1981).

Larvae of this species are presently unknown. McDowall (1980) suggests that, as with all other centrolophids, the young of *S. caerulea* are surface living. Grimes & Robertson (1981) illustrate yolk-sac larvae of *S. brama*, and Frentzos (1980) has photographs of a yolk-sac larva and late-larva (16.2 mm TL) of *S. brama* also. Robertson (1973) has also illustrated a 50 mm FL *S. brama*. Horn & Sutton (1996) report that juvenile *S. brama* reach a mean length of between 20 and 25cm FL in their first year of growth and that the smallest specimens captured (12 - 18cm FL) appeared in their study after February-March. It is likely that *S. caerulea* have similar morphology, growth patterns, and settlement sizes to *S. brama.*

Pre-juvenile specimens in this study (Ref. Collection CE) were collected very infrequently during summer months (January - February). Only three pre-juveniles were collected which could be positively identified as *S. caerulea*. One possible larval candidate (Ref. Collection AS) was also captured and is included in this section for comparison. However, this specimen is not positively

identified and the identification is based upon the timing of capture (October), relative size (9.2 mm TL), body shape, and the length of the maxilla (which is the same as the pre-juveniles). The meristic counts are much higher than might be expected if it is *S. caerulea*, and the absence of pre-opercular spines suggests that this identification may be erroneous. These were all collected in daytime surface plankton tows and at 3 sites. Two were captured at the 2 km site, one at the mouth of the Kowhai river, and one at the 6 km site. The capture of pre-juveniles at the surface validates McDowall's (1980) suggestion that young of this species are surface-living.

The larval candidate (Fig. 2.41 a) has a total length of 9.2 mm and is post-flexion. The body is moderately compressed and has no pelvic fins at this stage. The maxilla reaches to half-way below the orbit. No spines are present on the pre-operculum. The dorsal, anal, and caudal fins are separated and rays are evident. Meristic counts at this stage are (Dorsal) 85 and (Anal) III,55. The origin of the dorsal fin is above the posterior margin of the orbit, but the fin is reduced in height anterior to the anus. The anus is positioned slightly forward of mid-body (42% TL). The caudal fin is not yet forked. Pigmentation is already extensive on the body and head with many small stellate melanophores visible. The background colour is a light brown. Pigmentation is absent from behind a point approximately halfway between the anus and the caudal peduncle.

At 27.9 mm FL (Fig. 2.41 b) the pelvic fins are present and thoracic. The anus is located slightly posterior to mid-body (52% TL). The dorsal fin origin is above the pectoral fin insertions. Mean meristic counts of two specimens (27.8 mm and 33.3 mm TL) are (Dorsal) VIII, 30, (Anal) III, 22, (Pectoral) 20, and (Pelvic) I, 5. Ten prominent spines are present on the posterior edge of the pre-operculum. Pigmentation is very extensive and is only absent from the caudal peduncle. Stellate melanophores are present across most of the body with punctate pigmentation present between them. The gut region and parts of the pre-operculum and operculum are silver-white with some punctate pigment present also. Melanophores are present on all fins except the caudal fin. The overall appearance is of three dark vertical bars at mid-body, below the dorsal fin termination, and half-way between them, respectively. Metallic-silver colouration is present laterally on the myomeres.

At 40.6 mm FL (Fig. 2.41 c) the caudal peduncle is pigmented and the three vertical bars on the body are much more difficult to see. There is some suggestion of longitudinal stripes of darker and lighter pigment forming. This is consistent with McDowall's (1980) observations on juvenile (c.200 mm FL) colouration. The spines on the pre-operculum are slightly less prominent. Meristic counts of one specimen at this stage are identical to those taken from the two smaller pre-juveniles. There is still no pigmentation on the caudal fin. Otolith increments were counted for this specimen and 157 increments were visible with the light microscope at 1000X magnification. If these are daily increments then the larvae would have been spawned in late August.

Identification of these pre-juveniles is based upon meristic counts of the dorsal and anal fins, as well as the presence of prominent pre-opercular spines. McDowall (1981) reviews the centrolophid fishes present in New Zealand and a summary of modal meristic values, along with meristic values from the pre-juveniles in this study, are presented in Table 2.22.

Table 2.22 Meristic counts of three centrolophid species from McDowall (1981), and of three pre-juveniles captured in this study.

	S. punctata	*S. brama*	*S. caerulea*	Pre-juveniles (this study)
Dorsal	VIII, 37	IX, 27	VIII, 31	VIII, 30
Anal	III, 23	III, 22	III, 22-23	III, 22
Pectoral	20	20	21	20

From the dorsal fin ray counts, the pre-juveniles are unlikely to be *S. punctata* or *S. brama*. The observed counts are within the range of values observed for *S. caerulea* by McDowall (1981). Pre-opercular spines are visible in McDowall's (1981) illustrations of *S. caerulea*, but not *S. brama* or *S. punctata*. This also indicates that these specimens are *S. caerulea*.

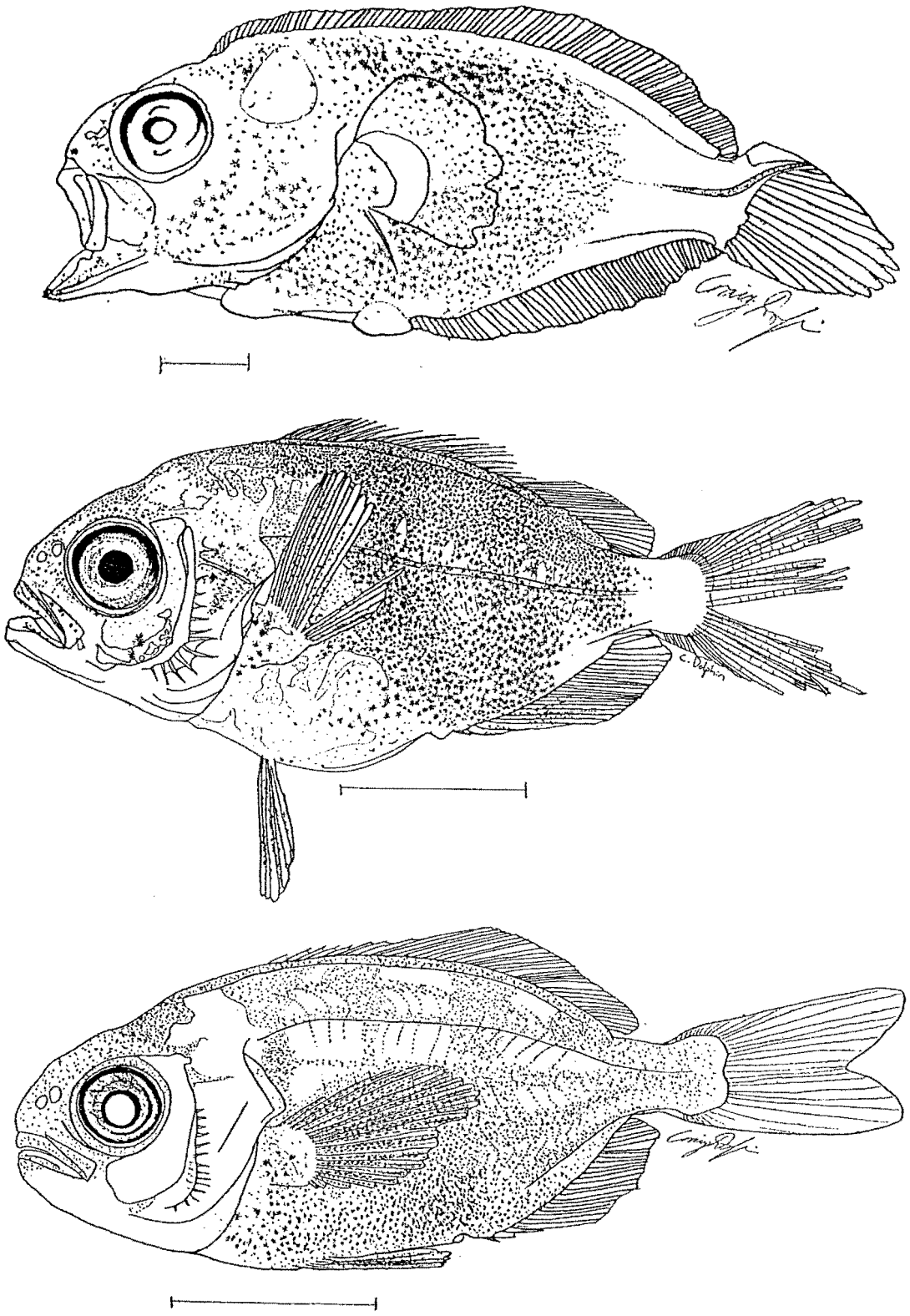

Figure 2.41 Possible-larva, and pre-juveniles of *Seriolella caerulea*

a) 9.2 mm TL (scale = 1 mm)

b) 27.9 mm FL (scale = 6 mm)

c) 40.6 mm FL (scale = 10 mm)

2.15 Order Pleuronectiformes

Family Bothidae

Arnoglossus scapha (Bloch & Schneider) **Witch**

The witch is a predominantly southern flatfish species which spawns from at least August until January (Robertson, 1973). The eggs are between 0.775 and 0.875 mm in diameter with a single colourless oil droplet which is between 0.112 and 0.125 mm in diameter (Robertson, 1975).

Early larvae possess a distinctive 'dorsal tentacle' and have a characteristic vertical pigment bar across the tail (Robertson, 1973). The dorsal tentacle disappears before fin ray formation and prior to metamorphosis. Robertson (1973) states that metamorphosis (the migration of the right eye to the left side of the head) does not occur as early as in other flatfishes (i.e. 10-15 mm) but rather that the pre-metamorphosis larvae remain pelagic until a size of 20 - 30 mm TL is attained. The prolonged pelagic phase and the rather weak and transparent morphology led Robertson (1973) to describe the larvae of this species as 'leptocephalus-like'. He also commented that this long pelagic phase may make the larvae useful as planktonic indicator species for the Southland Current. He argued that the presence of larvae of this species would enable the influence of the Southland Current to be detected where convergence with other water currents may confuse interpretation of physical indicators (such as temperature or salinity).

Specimens in this study (Ref. Collection CP) were collected in daytime plankton tows on one day during January 1997 in Fifth Bay, Kaikoura. The larvae were all dying upon removal from the net and none survived the return to the laboratory. Half of the larvae were preserved in 2% buffered formalin and half in 95% ethanol.

The larvae ranged in length from 20 - 40.5 mm and none had undergone eye migration. They were all transparent in life with three prominent pink-orange spots evenly spaced along the base of the dorsal fin and another four along the base of the anal fin (Fig. 2.42). Apart from size there were no discernible differences between larvae of 20 mm and 45 mm TL.

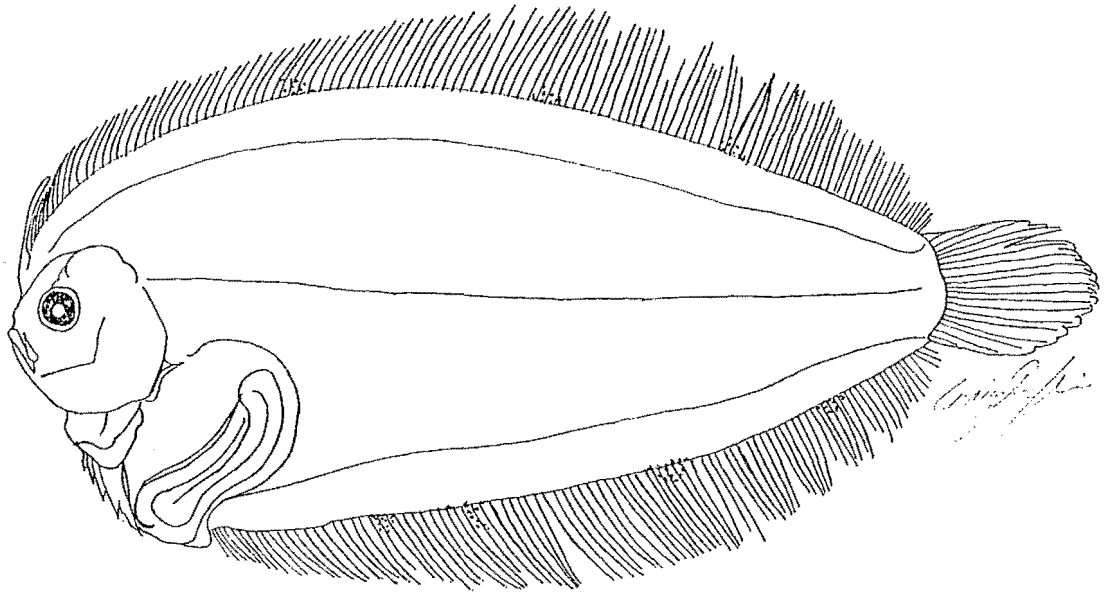

Figure 2.42 Larval witch (*Arnoglossus scapha*) 40.5 mm TL

Family Pleuronectidae

The early life history of pleuronectid larvae is unusual. During the planktonic phase the larvae become asymmetrical with the left eye migrating dorsally around the head and becoming adjacent to the right eye. Juveniles and adults of this family characteristically live on their sides. Five species (*Peltorhamphus novaezelandiae, Pelotretis flavilatus*, *Rhombosolea plebeia*, *Rhombosolea retiaria*, and *Colistium guntheri*) are known from the Kaikoura area (Edward Percival Field Station teleost species record).

Family Pleuronectidae

Colistium guntheri (Hutton) **Brill**

Spawning of brill occurs from winter to spring (Robertson, 1975; Graham, 1956) and the eggs are between 1.000 and 1.080 mm diameter and possess 14 - 26 oil droplets. Oil droplet diameters range from 0.06 - 0.10 mm (Robertson, 1975). Eggs described by Anderton (1906) with the common name 'brill' and a scientific name *Caulopsetta scapha* are more likely to be from turbot (*Colistium nudipinnis*) from their size (1.7 mm Ø) and description of having a large number of oil globules (see Robertson, 1975). Larvae of brill are undescribed at any stage of development.

Only one specimen (Ref. Collection G) was recognised in this study. This was captured in a daylight plankton tow at the surface in mid-November 1995 approximately 100m offshore from a fine shingle beach in South Bay. The late-larva was alive upon removal from the net. No attempt was made to keep the larva alive.

The late-larva is 25 mm TL (Fig. 2.43) and has a more solid body than *Arnoglossus scapha*. The left eye is not yet past the dorsal midline as it migrates to the right side of the head. The dorsal fin is deflected below the position of the eye, on the left side, and the origin is marginally in front of the orbit. Both pelvic fins are present although the left pelvic is much reduced. The right pelvic is joined to the base of the first anal fin ray. All fin rays are visible and meristic counts of this specimen are (Dorsal) 93, (Anal) 71, (Right pelvic)

10, and (Left pelvic) 5. Pigmentation on the body and fins is heavy except on the caudal peduncle, the caudal fin, and the posterior part of the dorsal and anal fins. Three distinct blocks of pigment are present on the dorsal fin, and two on the anal fin.

Metamorphosis of this species appears to occur at a much later stage than is seen in any *Rhombosolea* spp., but has already begun at this size. *Arnoglossus scapha* (this study; Robertson, 1973) and *Lophonectes gallus* (Crossland, 1981; Robertson, 1973) have not yet begun to metamorphose at lengths up to 40 mm TL and 30 mm TL respectively.

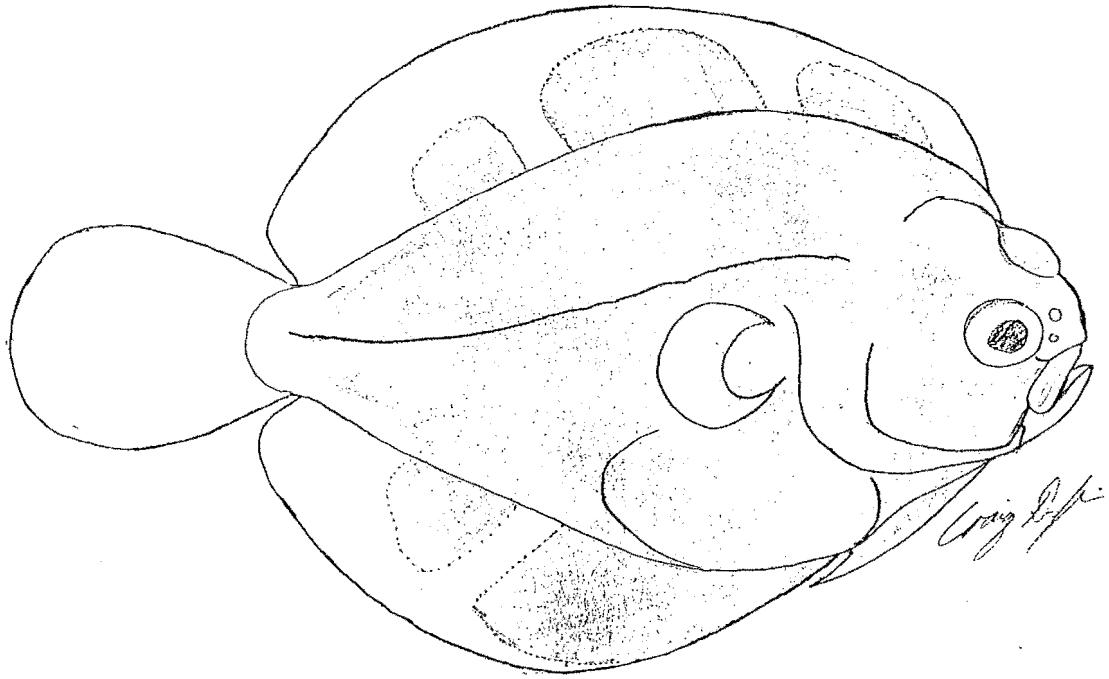

Figure 2.43 Late-larval brill (*Colistium guntheri*) 25 mm TL

Family Pleuronectidae

Peltorhamphus novaezelandiae (Günther) **Common Sole**

Common sole are winter-spring spawners and the eggs are abundant in South Island neritic waters. They range in diameter from 0.625 - 0.675 mm and have 2 - 6 oil droplets. The oil droplets range in size from 0.075 to 0.100 mm (Robertson, 1975). Yolk-sac larvae up to 2 mm TL have been illustrated by Robertson (1973, reproduced in Kingsford & Barrington, (1986)). Larger larvae are only known from a photograph of a 13.3 mm TL specimen in Frentzos (1980). Kingsford & Barrington (1986) asserts that these are likely to be similar to larvae of the speckled sole (*Peltorhamphus latus*) which are fully described (Roper, 1979, 1981; Crossland, 1981; Frentzos, 1980). It is difficult to make comparisons to the photographs in Frentzos (1980).

Specimens in this study (Ref. Collection AA) were collected in both day and night surface plankton tows in South Bay during late summer (February, 1996). These were all viable upon removal from the net and readily adapted to captivity. One was reared to a size of 45 mm TL on a diet of brine shrimp nauplii.

The smallest specimen captured was 9.8 mm TL (Fig. 2.44 a) and is already recognisable as a sole. Flexion has occurred and the left eye has completed its migration. The dorsal fin originates immediately at the mouth and extends back to the caudal peduncle. Two pelvic fins are present although the left pelvic fin is reduced. Pigmentation is similar to that of the speckled sole but no distinctive line of elongate melanophores is present along the dorsal body contour. Small, regularly-spaced pigment spots are present on both dorsal and anal fins.

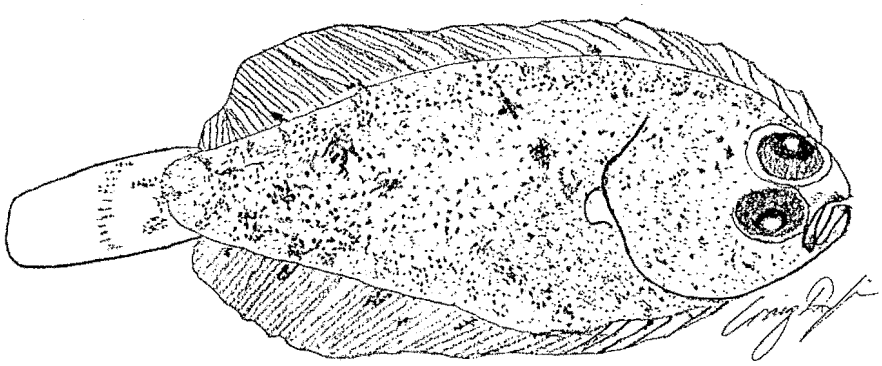

Figure 2.44 Pre-juvenile of the common sole (*Peltorhamphus novaezelandiae*) 9.8 mm TL

Family Pleuronectidae

Rhombosolea plebeia (Richardson) **Sand Flounder**

Sand flounder are spring-summer spawners (Colman, 1973; Robertson, 1975) whose eggs are between 0.575 and 0.725 mm diameter, with 2 - 13 copper coloured oil droplets. The copper colouration decreases as the embryo develops (Robertson, 1975). Robertson & Raj (1971) photographed the full development of the embryo, yolk-sac larvae, and early-stage larvae. Late stage larvae and pre-juveniles are photographed in Kilner (1974). Larvae and pre-juveniles are illustrated in Roper (1979, 1981), and Crossland (1981).

Specimens in this study (Ref. Collection B) were very abundant over sandy substrates and in South Bay during summer months. They were captured in daylight plankton tows at the surface, 1 m, and 3 m depth. Most remained viable after removal from the net and were easily adapted to the laboratory. They fed voraciously upon brine shrimp nauplii and would also eat small pieces of chopped up mussel from a length of 20 mm TL.

The smallest specimen recognised in this study was 9 mm TL (Fig. 2.45 a) and has a distinctive diamond-shape due to the dorsal and anal fins coming to a point. This shape is not seen in other flatfishes captured in this study. A series of U-shaped areas are present along the dorsal and ventral body contours which are non-pigmented. The dorsal fin origin is still behind the eye at this stage as the left eye has yet to complete its migration. This occurs by the time the larvae have reached 10 mm TL. The presence of spines on the head is not obvious. Pigmentation is heavy on the ocular side and is present on the head and most of the body. Sand flounder can be distinguished from black flounder (*Rhombosolea retiaria*) which do not have heavy pigmentation on the head and have prominent spines on the head. Eldon & Smith (1986) suggest a method to separate juveniles of sand flounder and yellow-bellied flounder (*Rhombosolea leporina*) on the basis of the position of the dorsal fin origin, in relation to the length of the head. This method does not help distinguish larvae or pre-juveniles of these species as the dorsal fin origin does not migrate forward of the eye until the eye has completed its migration to the right side of the head. Roper (1979) states that larvae of these species may be separated

by the relative development of the cephalic spines with these spines being less well-developed in larvae of *R. leporina*. However, this is a very subjective assessment and more work needs to be done before these two species can separated during larval and pre-juvenile development.

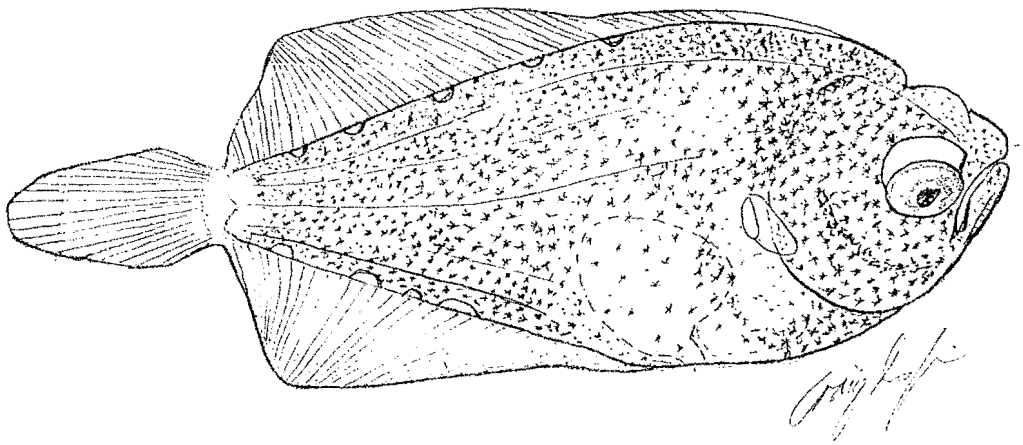

Figure 2.45 Partial development of sand flounder (*Rhombosolea plebeia*) 9 mm TL

Family Pleuronectidae

Rhombosolea retiaria (Hutton) **Black Flounder**

Black founder are the most poorly studied species in this genus. Spawning times and egg characteristics are unknown. Roper (1979) illustrated a 10.1 mm TL specimen (reproduced in Eldon & Smith (1986)). These are relatively easy to separate from sand flounder (*Rhombosolea plebeia*) and yellow-bellied flounder (*Rhombosolea leporina*) by the presence of very prominent spines on the head which persist to a size of at least 25 mm TL (Eldon & Smith, 1986).

Only two specimens were captured in this study (Ref. Collection C). These were both collected in one daylight tow on November 3 1995 at a depth of 3m below the surface in South Bay. Both were c. 10 mm TL and were dead upon removal from the net.

At 10 mm TL (Fig. 2.46) the left eye has not completed its migration to the right side of the head. The general colouration is an ochre-brown which differs to the overall grey appearance of sand flounder. Pigmentation is more sparse than in *R. plebeia*, and is more restricted to the middle part of the body. There are two distinctive lateral rows of melanophores present along the ocular side of the body. The presence of a prominent spine on the dorsal part of the operculum and two more in a rising line posterior to the eye also enable this species to be separated from sand flounder and yellow-bellied flounder. Less-prominent spines are present on the ventral edge of the operculum and above and behind the eye.

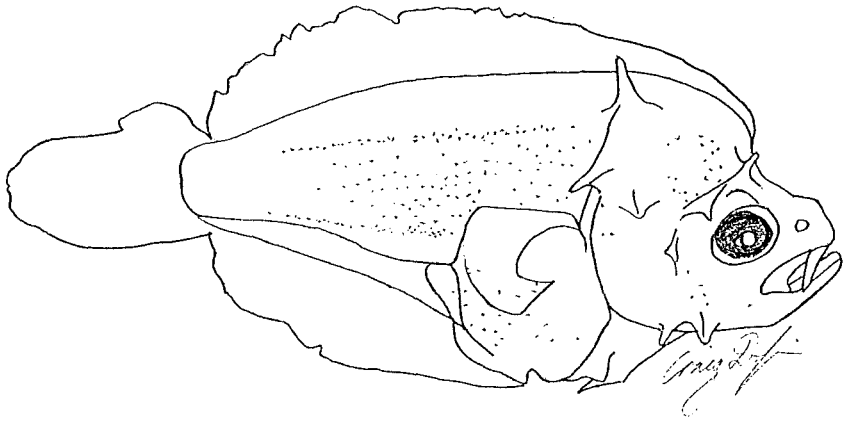

Figure 2.46 Late-larval black flounder (*Rhombosolea retiaria*)10 mm TL

2.16 Order Tetraodontiformes

Family Monacathidae

Parika scaber (Bloch & Schneider) **Leatherjacket**

With the exception of snapper (*Pagrus auratus*), the leatherjacket is probably the best studied larval fish in New Zealand. Spawning peaks are in spring in the Hauraki Gulf (Crossland, 1981), and summer in Otago Harbour (Robertson, 1975). The eggs are 0.650 -0.725 mm in diameter, with a single oil droplet that is 0.150 mm in diameter, and have a non-segmented yolk (Robertson, 1975). Crossland (1981) extended this description to include eggs from 0.64 - 0.74 mm diameter with an oil droplet diameter between 0.13 and 0.18 mm. He also commented on the remarkable clarity of the yolk, and that the perivitelline space narrows markedly during development (0.06 - 0.08 mm in the early stages). Embryonic pigmentation consists of two lines of inconspicuous melanophores (Crossland, 1981, pg. 50, fig.64).

All stages of larval development for this species are known. Roper (1981) illustrates early stage larvae of 3.1 and 3.5 mm TL (reproduced in Kingsford & Barrington, 1986). Elder (1966) illustrates a developmental series from 4.6 mm TL up to 21.2 mm TL (pgs. 86 & 87, text-figures 14 & 15). Crossland (1981) also illustrates two leatherjacket larvae (pg 53, fig. 67) of 4.5 mm TL and 6.7 mm TL. Kingsford & Milicich (1987, pg 74, fig. 8) illustrate a four-stage developmental sequence of larvae from 3.8 mm TL to 12.6 mm TL, and Thompson (1983) contains two photographs of *P. scaber* larvae (no scale is given).

Size at hatching is c. 3 mm TL. From Kingsford and Milicich (1987) the developmental sequence is as follows. The dorsal spine bud is the first feature formed at c. 3.5 mm TL with the spine itself forming almost immediately thereafter. Dorsal and anal rays appear (c. 6 mm TL) prior to flexion and caudal fin ray formation (c. 6.5 mm). By 12 mm TL the pre-juveniles are well pigmented, and some begin to settle onto reefs at this stage. This sequence agrees with illustrations by Crossland (1981), Elder (1966), and Roper (1981).

Evidence from Kingsford and Choat (1985) and Kingsford and Milicich (1987) suggests that these larvae are capable of settling on clumps of drift algae once a size of 8 mm TL has been attained. Pre-juveniles show a strong

behavioural preference for associating with drift algae once they are capable of doing so. However, most pre-juveniles appear to delay settlement onto rocky reefs for an extended period of time. Although they are capable of settlement onto rocky reefs at sizes as small as 12 mm TL (Kingsford and Milicich, 1987), pre-juveniles are still found associated with drift algae at sizes up to 35 mm (Kingsford & Milicich, 1987).

Sagittal otoliths of *P. scaber* have been shown (Kingsford & Milicich, 1987) to have daily growth rings (validated by tetralysal fluorescent marking) with the first increment laid down at the end of the first day after hatching. Growth is allometric from hatching to flexion, and linear from flexion to settlement. However, length at age is highly variable in this species (Kingsford & Milicich, 1987).

Specimens in this study (Ref. Collection CQ) were captured over a long period of time but mainly during late summer and early autumn (February-April). They were captured in daylight plankton tows at the surface of South Bay. Some were also collected at the 2 km site.

All individuals in this study were pre-juveniles (Fig. 2.47) and did not deviate from previous descriptive accounts given by Crossland (1981), Elder (1966), and Kingsford & Milicich (1987).

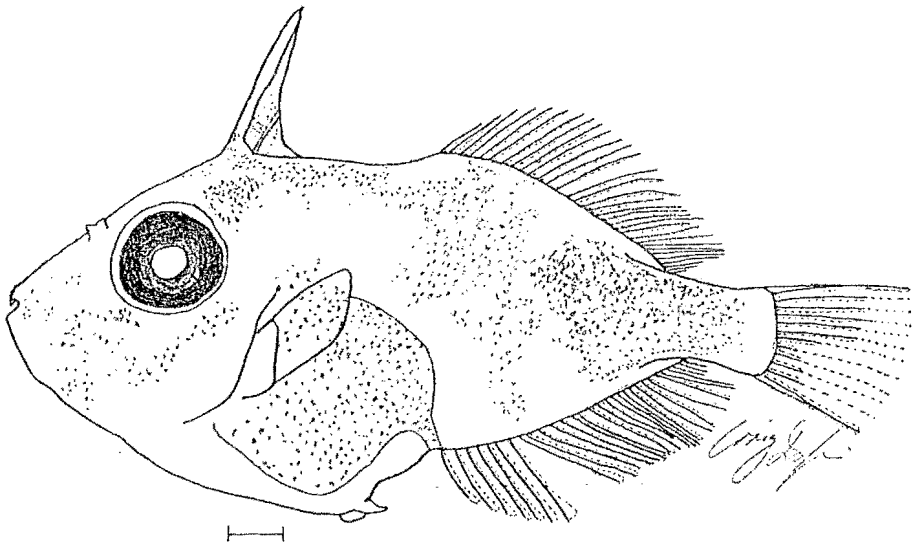

Figure 2.47 Pre-juvenile leatherjacket (*Parika scaber*) 16.6 mm TL

The aim of this study was to identify and describe previously unidentified larval fishes, and to extend descriptions of those species that are already described elsewhere. In this study a total of 43 species were identified (Table 2.1). Of these, 17 were identified for the first time as larvae. This raises the number of fish species identified as larvae or pre-juveniles in New Zealand to 110 (see Appendix D). Previous knowledge of the development of 14 other species has also been extended by this work.

Commercially exploited species described for the first time were the larvae of bigeye seaperch (*Helicolenus barathri*), pre-juveniles of white warehou (*Seriolella caerulea*), and pelagic juveniles of red cod (*Pseudophycis bacchus*). Also of interest is the correction to the illustration of butterfish (*Odax pullus*) larvae in Kingsford & Barrington (1986). Other commercially exploited species included in this work are blue cod (*Parapercis colias*), barracouta (*Thyrsites atun*), yellow-eyed mullet (*Aldrichetta forsteri*), spotted stargazer (*Genyagnus monopterygius*), common sole (*Peltorhamphus novaezelandiae*), sand flounder (*Rhombosolea plebeia*), and leatherjacket (*Parika scaber*).

Further work on larval fishes in Kaikoura is sure to encounter species not included in this work. Several species that were found in this study, but could not be identified, are included as an appendix.

This work brings together information pertinent to the early life history of the 43 identified species in a single work. Previously, this information was scattered across the literature, both published and unpublished, and was difficult to access.

Accessibility to larval fish information in New Zealand remains difficult and there is still the need for a published guide to bring together information for all species that are known as eggs, larvae, and pre-juveniles in New Zealand. Such a publication should follow the recommendations of Leis (1993) for maximum usefulness. In particular, line drawings should be used in preference to photographs and a reference collection of type specimens should be maintained where possible.

As an aid to future workers on larval fishes in New Zealand, a bibliography of references that are not included in this work, but are relevant to New Zealand species, is provided as an appendix.

The status of early life history descriptions in New Zealand is still low in comparison to other areas of the world. Descriptions of some stage of the early life history now exist for c. 12% (110 species) of New Zealand's teleost fishes, which is an improvement on the previous level of c. 10% (93 species). Another 2% (18) of species are identified as eggs but not larvae. However, it must be remembered that these figures are likely to be over-estimates since they are based upon a total of 923 teleost species being found in New Zealand (Paulin *et al.*, 1989). More species have been described from New Zealand since 1989 (e.g., Nafpaktitis *et al.* 1995).

One of the most interesting aspects of this study was the absence of many species that had originally been anticipated. For example, Tarakihi (*Nemadactylus macropterus*) eggs were collected at Kaikoura by Robertson (1973) and it was anticipated that larval Tarakihi would be collected during the period of this study. Despite an extensive sampling effort throughout two years (Hickford, PhD in progress), no larvae resembling the yolk-sac larvae illustrated by Robertson (1973) were collected. Similarly, other species (e.g., groper (*Polyprion oxygeneios*), red moki (*Cheilodactylus spectabilis*), blue moki (*Latridopsis ciliaris*), banded wrasse (*Notolabrus fucicola*), kahawai (*Arripis trutta*), ling (*Genypterus blacodes*), etc.) were absent or not recognised from this study. These species are all common as adults in the study area (e.g., Hickford & Schiel, 1995) and the absence of so many common species as larvae was surprising.

One explanation for the absence of some prominent species is that some species (e.g., groper) migrate north to spawn near East Cape (Roberts, 1996). However, many common reef-fish species are unlikely to migrate out of the study area to spawn (e.g., banded wrasse) and so migration does not satisfactorily explain the absence of larvae.

It is possible that eggs of these species were collected but not recognised. For example, eggs of the locally common butterfish (*Odax pullus*) were collected and reared, but no larvae were collected from plankton tows at any stage. This suggests that even when eggs are collected, the larvae that hatch from them may not necessarily inhabit the same habitat. Ritchie (1969) speculated that larval butterfish settle onto macroalgae immediately after hatching.

It is also possible that the larvae remain pelagic but occupy a deeper position in the water column than is generally sampled in plankton studies. Most samples in this study were taken at the surface, with some samples taken from depths of 1 m or 3 m below the water surface. Grieve (1966) found that the greatest abundance of larval teleosts in Kaikoura occurs at a depth of 22 m below the water surface. Overseas experience has shown that larval fishes do exhibit depth preferences and vertical migratory behaviour (Russel, 1928; Batty, 1994).

There is also the possibility that some larvae are particularly strong swimmers that actively evade capture in plankton nets towed at slow speeds. These may be absent from plankton samples even if they are present at the depth and location of plankton tows. It is therefore probable that many other species are present as larvae in Kaikoura but were missed by the sampling methods employed in this study.

Another factor that may partly explain the absence of some species from this study may be that after spawning occurs, larvae are swept away by water currents, before being sampled. The principal reason for interest in larval fish assemblages in Kaikoura is the presence of the subtropical convergence between the Southland and East Cape currents (Heath, 1971). This convergence zone may also act as a conveyer system that sweeps larvae out into the Pacific Ocean. If this occurs then it is possible that species with short, well-defined spawning periods may be missed as a result of sampling before and after the eggs and larvae have been produced and swept away.

This conveyor system creates problems for coastal species that require coastal habitat for settlement. Banded wrasse, for example, will be unable to settle in depths associated with oceanic habitats. This raises important questions about how larval fishes remain close to suitable habitat in the presence of strong water currents that would presumably displace larvae into unsuitable habitats. Kingsford & Choat (1986) suggest that mechanisms for this may include onshore transport in internal waves. Also of potential importance are prevailing wind conditions and floating debris such as macroalgae.

A good understanding of processes that affect abundances, growth, and survival of larval fishes is necessary to any ecological investigation of larval fishes. Environmental factors such as temperature, hours of sunlight, prevailing

wind conditions, turbulence due to wave action, upwelling events, thermoclines, availability of prey, and presence of predators may all contribute to patterns of abundance, distribution, growth rates, and behaviour (Blaxter, 1984). These factors may also change in importance as larvae develop. Large larvae, for instance, are reported to be less sensitive to starvation (Theilacker & Dorsey, 1980) and less subject to predation (Hickey, 1979, 1982) than small larvae.

Growth rates are of particular interest because they may partly explain differences in larval survival and consequent recruitment of juveniles into fisheries (Underwood & Fairweather, 1989). Otolith studies are the primary tool for ageing and estimating growth rates for larval fishes (Brothers, 1984; Casselman *et al.*, 1987). Otoliths of most species have daily growth increments which can be counted to age individual larvae accurately (Jones, 1985). This information can be used to calculate growth rates. However, some species have non-daily incremental growth in their otoliths (Campana & Neilson, 1985; Jones, 1985), and rates of increment formation should be investigated for species of interest.

In New Zealand, only snapper (*Pagrus auratus*) and leatherjackets (*Parika scaber*) have been investigated for otolith-increment formation rates and age at length estimates based on these. Both species have daily growth increments in their otoliths and highly variable growth rates (Kingsford & Milicich, 1987; Kingsford & Atkinson, 1994). Combining ages of wild-caught larvae with the location of capture and known drift rates of water currents may also enable estimates to be made regarding the location of spawning grounds (Townsend & Graham, 1981).

Once factors affecting larval fish survival and growth are understood, then questions about the stock-recruitment relationship, mechanisms of larval retention in an area, and patterns of observed abundances, can be answered more meaningfully. Potentially, monitoring of environmental conditions in combination with regular ichthyoplankton surveys may provide advance warning about years of weak recruitment to a fishery and play a supplemental role in fisheries management. This has already been used on a limited basis for some northern hemisphere species such as Californian pilchards (Sette & Ahlstrom, 1948) and North Sea plaice (Simpson, 1959). Crossland (1980) provides an

instance of using the abundance of snapper eggs to indicate the stock-size of snapper in the Hauraki Gulf.

The usefulness of larval fish studies is not limited to ecological or fisheries investigations. Classification of animal groups is based mainly on phenetic approaches. Where ontogeny is well understood, structures that have traditionally been assumed to be homologues in different groups may be found to be analogues (see Cohen, 1984 for review). Thus, by understanding the embryological and larval ontogeny of species it may be possible to classify groups of fishes more accurately.

The potential usefulness of ichthyoplankton studies in New Zealand remains relatively untapped. Significant advances in identification of local fish larvae are required before this potential can be realised. This may not occur unless methods for collecting larvae at greater depths are used. This would require the use of large research vessels that can support equipment for plankton tows down to depths of several hundred meters, preferably with onboard facilities for keeping collected eggs and larvae healthy until they can be placed in a suitable aquaculture facility.

More success is likely to be had with rearing fish larvae hatched out of wild-caught eggs than with wild-caught larvae. This is because capture related stress and damage has less effect on eggs than larvae.

Rearing larval fishes requires a more advanced aquaculture technique than could be applied in this study. Logistical difficulties with maintaining large enough cultures of phytoplankton and, in turn, prey organisms limits the volume in which fish larvae can be reared with suitable prey densities. Large tanks with adequate supplies of suitable prey items are more likely to be successful environments for rearing larval fish than the small tanks used in this work. Work must also be done to ascertain the most successful lighting and turbulence conditions for larvae. These may differ for species collected from greater depths than those collected at the surface.

As with most aquaculture applications, water quality is very important. Techniques allowing for the exchange of water and that avoid the loss of larvae or prey are necessary. Also, the type of prey organisms suitable for rearing different stages of larval development must be ascertained. Problems were

encountered in this study when attempting to wean larvae onto brine shrimp nauplii from feeding on rotifers.

It is generally acknowledged that ichthyoplankton surveys and intensive aquaculture facilities of the sort required are expensive (Robertson, 1973; Blaxter, 1984), and this may prove prohibitive to their use in New Zealand. However, if these logistical problems could be surmounted then it is likely that a much better understanding of the early life histories of New Zealand's teleost species could be attained. This would have potential ramifications for fisheries management, teleost taxonomy, and understanding ecological processes that effect species at a stage that is currently beyond our scope of knowledge.

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INTRODUCTION

Growth rates of larval fishes may influence the duration of the pelagic larval phase of a species. Underwood & Fairweather (1989) have shown that the number of larval stage animals surviving to settlement may depend on the duration of the larval phase. Thus, a faster growth rate may indicate a shorter larval phase, and consequently an increase in survival to settlement. It is possible to get estimates of growth rates by rearing larvae in the laboratory, but these figures are probably not useful since they have little or nothing to do with the conditions experienced by larvae in the natural environment. The only meaningful method of obtaining growth rates of larvae is to capture wild larvae and accurately age them. From this, one can calculate a size vs. age relationship to determine growth rates.

Many researches have tackled the problem of ageing wild-caught larval fishes. Methods trialed include analysing length/frequency distributions (e.g., Baker, 1972) and using visible and chemical markings of calcified structures (caused by incremental growth) as indicators of regular periods of time (Pannella, 1971; Casselman *et al.*, 1987; Saxena, 1994).

Length-frequency relationships are not particularly reliable as they depend on well-separated spawning events and low variation in growth rates. Many species of marine teleosts, for example butterfish (Ritchie, 1969) and triplefins (Elder, 1966), spawn repeatedly over an extended period of time. Also, laboratory work and aquaculture experience have shown that individuals of the same species vary greatly in their growth rates even under identical rearing conditions (e.g., Jones *et al.*, 1983).

Fish scales and other calcified hard parts exhibit incremental growth. This can be seen under the microscope as circular marks or increments. Most temperate species of fishes have increments in their scales that correspond to the age of the fish in years (annuli) (Hardy, 1959; Baker, 1972; Casselman *et al.*, 1987; Das, 1994). However, the reliability of using scales to age fish decreases as linear growth diminishes. Linear growth can cease, even if the height and width continue to grow (Lowerre-Barbieri *et al.*, 1994). More recently, there has been an interest in the microstructure of scales that may show daily growth increments (Pannella, 1971; Campana & Neilson, 1985; Kingsford &

Atkinson, 1994). The usefulness of this for ageing larval fishes is questionable because larval fishes often do not develop scales until late in their development. Consequently, it is impossible to accurately age larvae using this method prior to scale formation.

Structural bones, such as the opercle and cleithrum, and also spines (e.g., Saxena, 1981) have been used to estimate ages of fishes with some success. Most work, however, has focussed on otoliths (see Campana and Neilson (1985) for review). Otoliths are calcium accretions in the ear that are functionally associated with maintaining equilibrium (Casselman *et al*, 1987). Otoliths are initially tiny, calcified structures secreted in the otic capsules during embryological development. This area is referred to as the primordium in post-embryonic forms. Later growth of otoliths is the result of secretions by macular cells which form thin layers of protein (otolin) with calcium carbonate (usually aragonite) around the primordia. Each growth layer is bipartite, with a relatively wide 'incremental zone' that consists primarily of calcium carbonate embedded in the protein matrix, and a relatively narrow 'discontinuous zone' that consists primarily of the protein matrix with relatively little calcium carbonate (Campana & Neilson, 1985). Differences in refractive indices for these two zones allow the growth increments to be viewed using light microscopy. The incremental zone appears as a wide, translucent band and the discontinuous zone as a narrow, opaque band. Similarly, after etching for scanning electron microscopy, the incremental zone is a wide, raised band and the discontinuous zone is a narrow, deeply-etched band.

Comparatively large circular markings (annuli) in the otoliths of adult fishes are usually deposited annually as a result of differential growth during winter months and summer months. They have been used by fisheries researchers to estimate the ages of many fish species (e.g., Griffiths & Heicht, 1995; Horn, 1996; Horn & Sutton, 1996). However, these structures are of little use for ageing larval and juvenile fishes that are less than a year old.

More recently, the growth increments ('daily' rings) in the microstructure of fish otoliths have been of interest for ageing fishes prior to annuli formation. As with scales, these are usually assumed to be formed daily (Pannella, 1971; Jones, 1985; Kingsford & Milicich, 1987; Sepúlveda, 1994). However, environmental conditions have been shown to affect the rate of increment

formation (Campana & Neilson, 1985; Brothers, 1990; Radtke & Fey, 1996). This led Campana & Neilson (1985) to conclude:

> It is, therefore, imperative to establish the rate of increment formation for any species that are aged with this method.

Also, Casselman *et al.* (1987) urges:

> Validation should be an essential and routine part of every study that involves the extraction of age data from calcified structures of fish ... Because a specific type of interpretation and procedure has been demonstrated as valid for a particular species under certain conditions, it should not be assumed to be valid for other species and conditions.

Methods used to validate rates of increment formation rely on 'marking' part of the otolith and rearing larvae for a known period of time. Increments formed post-marking are counted and related to the length of time since the mark was made. Alternatively, larvae reared from hatching can be used to determine rates of increment formation.

Marking the otoliths of larval fishes can be achieved by several methods. Manipulating environmental conditions may cause the larvae to alter the pattern of increment formation. Overseas experience in trout fisheries shows that manipulation of the light-dark cycle can cause distinctly wider opaque and translucent increments in the otoliths of trout. Similarly, thermally stressing larvae may result in changes to increment width and formation rates (Brothers, 1990).

Immersion in solutions containing elements such as strontium, fluoride, copper, and zinc may result in the uptake of these elements into calcified structures formed during this immersion time (Brothers, 1990). Strontium, in particular, has been shown to mark statoliths successfully in squids (Hurley *et al.*, 1984) and in trout otoliths (Ophel & Judd, 1968; Brothers, 1990). The most common method utilised is that of immersion in marker dyes. Tetracycline has commonly been used to create fluorescence in otolith increments formed during the period of immersion (e.g., Beltran *et al.*, 1995; Martin, 1995). Other dyes that have been used successfully are calcien and calcien blue (e.g., Brooks *et al.*, 1994), and alizarin dyes, in particular, alizarin red and alizarin complexone (Blom *et al.*, 1994; Radtke & Fey, 1996).

Once the method and validity of counting 'daily' increments is established for a species, it is possible to age wild-caught larvae. From age estimates, growth rates can be obtained and these can be used to investigate the effects of environmental factors on larval fish growth, larval duration, survival to settlement, etc.

Very little work on ageing larval fishes has been done in New Zealand. The earliest research into ageing juvenile fishes in New Zealand was on the intertidal species, *Acanthoclinus fuscus* (Jillet, 1968). This was not an investigation into the microstructure of larval fish otoliths but was an attempt to validate annual rings for this species. Jillet observed that the otoliths from the smallest individual captured (10 mm TL) were completely opaque. He inferred this to mean that the newly settled larvae were less than 6 months old.

Baker (1972) used length/frequency distributions, the length of scales, and the increments visible in the scales, to age larvae and adults of pilchards (*Sardinops neopilchardus*). No attempt was made to use otolith increments for this purpose.

More recently, there has been some excellent research into daily growth increments found in the otoliths of larval snapper (*Pagrus auratus*; Kingsford and Atkinson, 1994) and leatherjackets (*Parika scaber*; Kingsford and Milicich, 1987). Both of these studies incorporated good validation techniques to confirm the age-at-length estimates. The current situation in New Zealand is that only these two species have validated daily growth-increment deposition and provide the only instances of age-at-length estimates based upon otolith microstructure.

I aimed to increase the number of species for which rates of otolith increment formation are known in New Zealand. If this could be achieved, I also hoped to be able to give length-at-age estimates for some species using data from otoliths of wild-caught larvae. However, little success was achieved using most of the methods trialed, and only limited numbers of otoliths were processed making this work a preliminary study that is included as an appendix to aid future workers.

METHODS

Otolith microstructures of *Stokellia anisodon*, *Diaphus* sp., *Gaidropsarus novaezelandiae*, *Scorpaena papillosus*, *Congiopodus coriaceus*, and *Aldrichetta forsteri* were examined for 'daily growth increments, and the rates of formation of these increments were investigated.

Extracting otoliths

Only sagittal otoliths were used in this study. These were removed from the otic capsules of larvae by dissecting the animals in a shallow dish (or on a microscope slide) in 95% ethanol, using needle-point forceps. It was easiest to extract otoliths through the roof of the mouth. An artist's paintbrush was used to pick up the small otoliths and transfer them to a clean microscope slide for mounting.

Mounting otoliths

Otoliths were mounted in two different media: Epoxy resin (Epotek 301) and Crystal Bond (Aremco Products). The epoxy resin was mixed at a ratio of 3 (part A) : 1 (part B) and left to react for 10 minutes. After this time, a small drop was placed onto a clean microscope slide and an otolith carefully placed concave-side down in the resin. The epoxy was left to set for 24 hours on a warm hot-plate.

The best method for mounting otoliths in Crystal Bond was to melt a small amount of Crystal Bond on a clean slide and place an otolith in this whilst it was still liquid. Care was taken not to overheat and boil the Crystal Bond, to avoid gas bubbles forming which could obscure the otolith. The medium set quickly and was re-melted several times when necessary for correct orientation of the otolith.

Preparation for Light Microscopy

Once the otoliths were mounted, they were ground using various grades of well-worn, wet carborundum paper (1500 grit, then 2000 grit). These were ground until the approximate mid-plane of the otolith was reached and then polished using a silk napping-cloth with colloidal silica polishing liquid to remove most of the grinding marks. If the increments were clear enough at this point, after

checking with a compound microscope, no further preparation was attempted. If the otolith was not very clear and the mounting media was Crystal Bond, then the otolith was turned over and ground and polished from the other side. It was sometimes helpful for better clarity to add a small amount of clean Crystal Bond when turning the otolith over.

Crystal Bond was found to be much easier to use and gave better results for light microscopy than the epoxy resin. This is because it is possible to grind and polish both sides of the otolith using this medium, whereas only one side can be ground and polished using epoxy resin.

All otoliths were viewed using a Wild compound microscope at 1000x magnification with immersion oil and the increments were counted three times to achieve consistency. Increments were counted in a straight line from the primordium to the otolith margin wherever possible. Unreadable sections were avoided by following the last clear increment around the otolith until increments became readable again.

Preparation for Scanning Electron Microscopy

Otoliths were mounted and prepared as for light microscopy study but with a longer polishing time. The portion of the microscope slide containing the mounting medium and otolith was cut out using a diamond cutting-knife. The otolith was etched in a weak solution of acid (7% EDTA; ethylenediaminetetra-acetic acid, buffered to a pH of 7.3 with NaOH) for three minutes. After etching, the otolith was cleaned in a strong flow of distilled water and dried in air. Then it was placed on a 2.5 cm diameter aluminium S.E.M. stub using a liberal amount of carbon glue to minimise charge build-up and signal flaring. The otolith was sputter-coated with 50 nm of gold before viewing with a Leica S440 scanning electron microscope operating at accelerating voltages of 15 - 20 kV. Images were recorded on Ilford Pan F-plus film (100ASA).

Counting Increments

Growth increments are bipartite and consist of a light 'band' together with an optically opaque 'band' that form concentric circles around the primordium. Increment counts were made by counting the number of opaque (dark) bands that were present between the centrally-located primordium and the margin of

the otolith. Counts were repeated three times for each otolith and the otolith was not used if the range of variation between counts was greater than c. 15% of the mean count.

Validation Experiments

Several small-scale attempts were made to investigate the periodicity of increment formation in larval fishes.

i) Marking Otoliths with Tetracycline

Twenty pre-juvenile common triplefins (*Forsterygion lapillum*) and one pre-juvenile spotty (*Notolabrus celidotus*) were immersed using a soft dip-net in a 1% tetracycline hyper-osmotic (5%) sea water solution for one minute. This was used in preference to a longer immersion period at a lower concentration, because the high concentration, short immersion-time method has been more successful in marking otoliths where these methods have been compared directly (Beltran *et al.*, 1995).

The pre-juveniles were returned to their rearing tanks and left under the natural light-dark regime for 10 days. These animals were fed three times daily with *Artemia* nauplii. After this time the otoliths were removed from the fish and mounted in epoxy resin. They were prepared for light microscopy and viewed using a Leitz Orthoplan vertical illuminator fluorescence microscope and ultraviolet excitation radiation to detect the presence and location of fluorescent markings. The filter combinations consisted of: 4 mm BG 38 and 2 mm UG 1, dichroic beam-splitting mirror, TK 400 and built-in suppression filter, K 400 with an additional suppression filter of K 460.

ii) Marking Otoliths by Manipulating Photoperiod

A single pigfish larva (*Congiopodus coriaceus*) was kept alive under the natural light-dark cycle for several days. Artificial lighting was then used to provide 96 hours (four complete days and nights) of constant light. Following this, natural lighting was resumed for one week before another 96 hours of constant light was provided. The larva was fed three times daily with *Artemia* nauplii throughout the experiment. The otoliths were removed, mounted in epoxy resin, and prepared for light microscopy.

iii) Labelling Otoliths With Strontium Chloride

A single, newly settled clingfish (*Diplocrepis puniceus*) was captured from the lower intertidal zone and placed in a 4 L tank of 300 mgL^{-1} strontium chloride / seawater solution for 18 hours (after Brothers, 1990). The specimen was then placed in a rearing tank and reared under natural light conditions for 10 days. *Artemia* nauplii were supplied three times daily.

The otoliths were removed, mounted in epoxy resin, and prepared for scanning electron microscopy. This time, however, the otoliths were coated in carbon instead of gold, in preparation for energy-dispersive x-ray microanalysis. The x-rays were collected and spectra produced using a Link ISIS system with a Pentafet atmospheric thin window, a built-in take-off angle of 35° and magnification of 1000x. The elemental map mode was also used to visualize the actual location of strontium emissions from the otolith.

iv) Marking Otoliths With Alizarin Complexone

As alizarin complexone is more successful at marking otoliths and the mortality rate of the fish is lower than with alizarin red S (Blom *et al.*, 1994), alizarin complexone was trialed on both smelt (*Stokellia anisodon*) and scorpionfish (*Scorpaena papillosus*).

- Stokell's smelt (*Stokellia anisodon*)

Eight larval smelts were captured alive at night using a bucket under a light, near a shingle beach in South Bay. These were transferred to holding tanks in glass jars (to avoid net damage) and held for 5 days before trials began. Five of the smelts failed to acclimatise and died. The remaining three smelts were feeding heavily and were seemingly untroubled by human disturbance after four days.

These were immersed in 30 mgL^{-1} alizarin complexone in filtered (5 μm) seawater for 26 hours (after Blom *et al.*, 1994). Thereafter, they were transferred back to their previous holding tank. Two of these fishes died the next day (one jumped out of the tank). The last smelt was maintained under a natural light-dark cycle for 18 days.

- Scorpionfish (*Scorpaena papillosus*)

Five scorpionfish pre-juveniles were captured alive at night using a bucket under a light, near a shingle beach in South Bay. One of these was used as a control and was not immersed in alizarin complexone. The remaining four were immersed in 30 mgL^{-1} alizarin complexone in filtered (5 μm) seawater, for 22 hours, before being moved into holding tanks with a natural light-dark cycle. One specimen died the day after being removed from the alizarin complexone solution. The remaining pre-juveniles were kept in natural light conditions for a period of 10 days before being immersed once more, in an identically prepared alizarin complexone solution as the first alizarin treatment, for a further 24 hours. Thereafter, the scorpionfish were kept under constant light conditions in holding tanks for another 9 days. This was to ensure that difficulties in counting increments accurately would not be compounded by refractive problems associated with the otolith margin.

All otoliths were removed, mounted in Crystal Bond, and prepared for light microscopy. Fluorescent markings were detected using a Leitz Orthoplan microscope excited with ultraviolet radiation as described earlier. An image of the markings was recorded on Fujichrome Sensa 400ASA colour slide film.

Age-at-length estimates

Larval fish of several species were captured in plankton tows and kept for use in age-at-length estimates. These were preserved in 100% ethanol before the total length was measured. Sagittal otoliths were later removed, mounted in Crystal Bond and prepared for light microscopy. Increments were counted using the light microscope at magnifications of 1000x. Some otoliths were then prepared for scanning electron microscopy and increments were counted again to compare methods. Species examined included *Stokellia anisodon*, *Diaphus* sp., *Gaidropsarus novaezelandiae*, and *Aldrichetta forsteri*.

RESULTS

Using light microscopy, each growth increment appears as a bipartite, circular ring consisting of a wide, translucent band (incremental zone) and a narrow, opaque band (discontinuous zone). When viewed under low power these appear as a series of concentric circles within the otolith structure (Plate A.1). At high power more increments are visible, and differences in increment widths and appearance are more clearly seen, than at low power (Plate A.2). The use of light microscopy allowed fluorescent markers, absorbed during otolith growth, to be detected (Plate A.3). The two fluorescent marks formed at known time-intervals allowed rates of increment formation to be determined (Plate A.4)

After etching for scanning electron microscopy, the incremental zone is a wide, raised band and the discontinuous zone is a narrow, deeply-etched band (Plates A.5, A.6). High magnifications using scanning electron microscopy can resolve very fine increments that are too narrow to be detected using light microscopy, and also may reveal details of the crystalline structure of the otolith (Plate A.7).

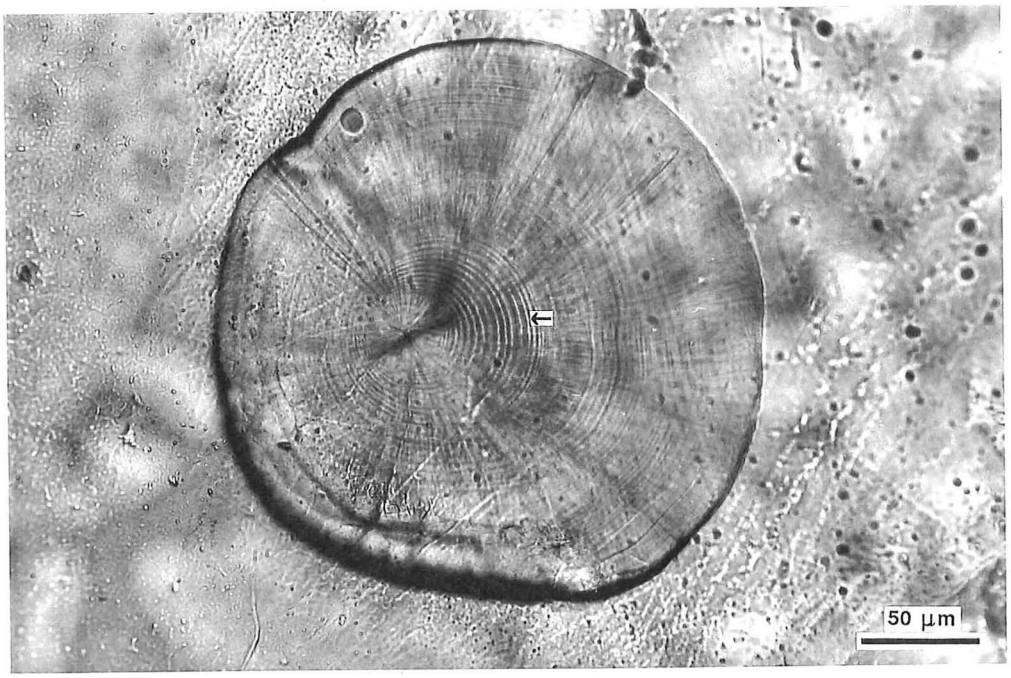


Plate A.1. Low power (220x) micrograph of a spotty (*Notolabrus celidotus*) otolith using light microscopy. The arrow indicates an area of the otolith with clear growth rings that appear as a series of concentric circles.

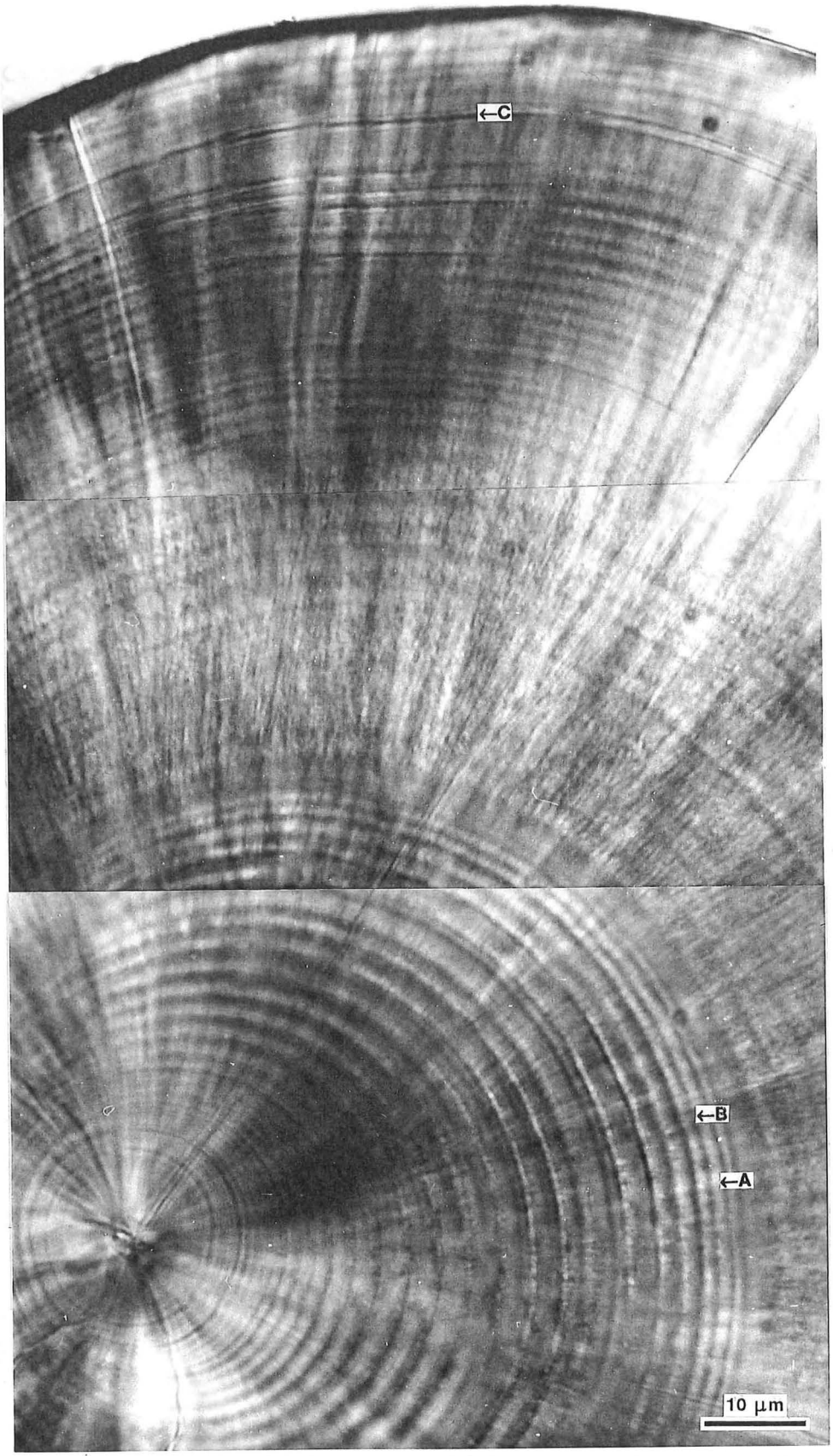


Plate A.2. Light micrograph of a spotty (*Notolabrus celidotus*) otolith at high power (1600x). Arrows A and B indicate a light ring (incremental zone) and a dark ring (discontinuous zone) that together make up a single growth increment. Arrow C indicates the position of an unusual increment at the expected position for validating daily increment formation.

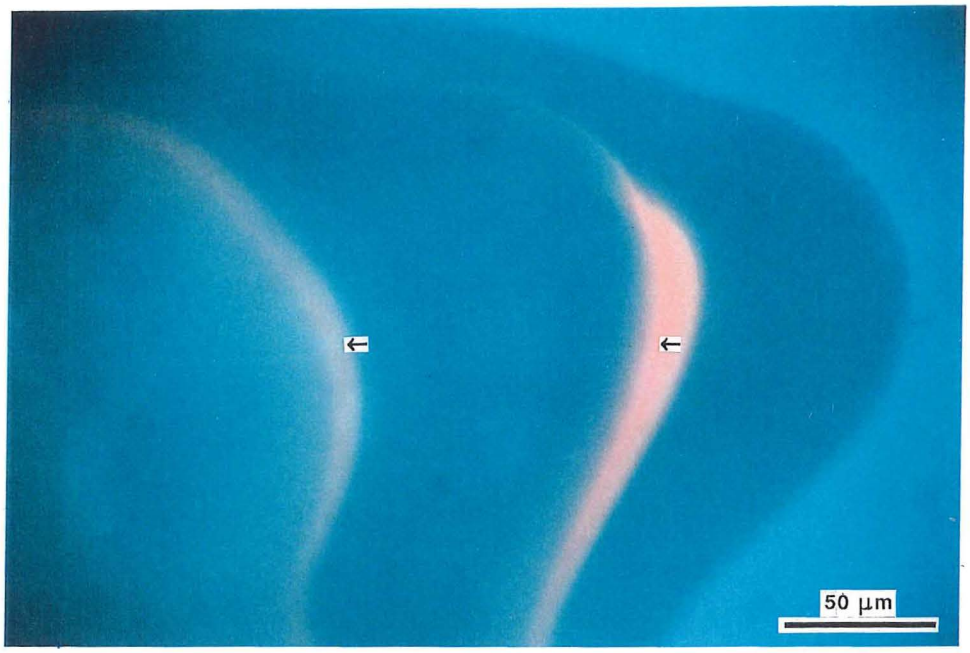


Plate A.3. View of a scorpionfish (*Scorpaena papillosus*) otolith showing red fluorescent marks (arrows) produced by immersion in alizarin complexone.

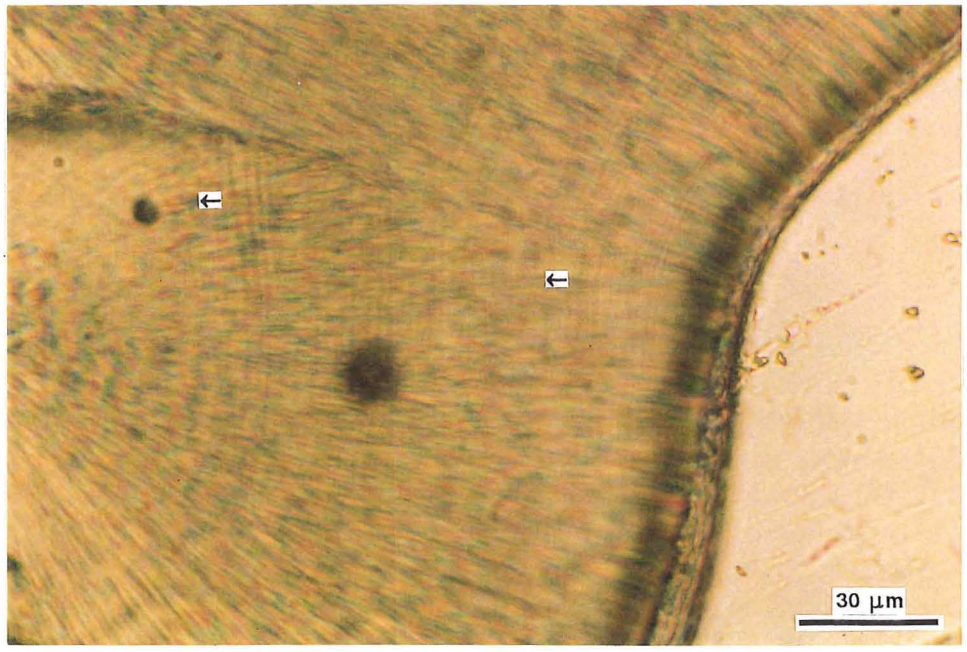
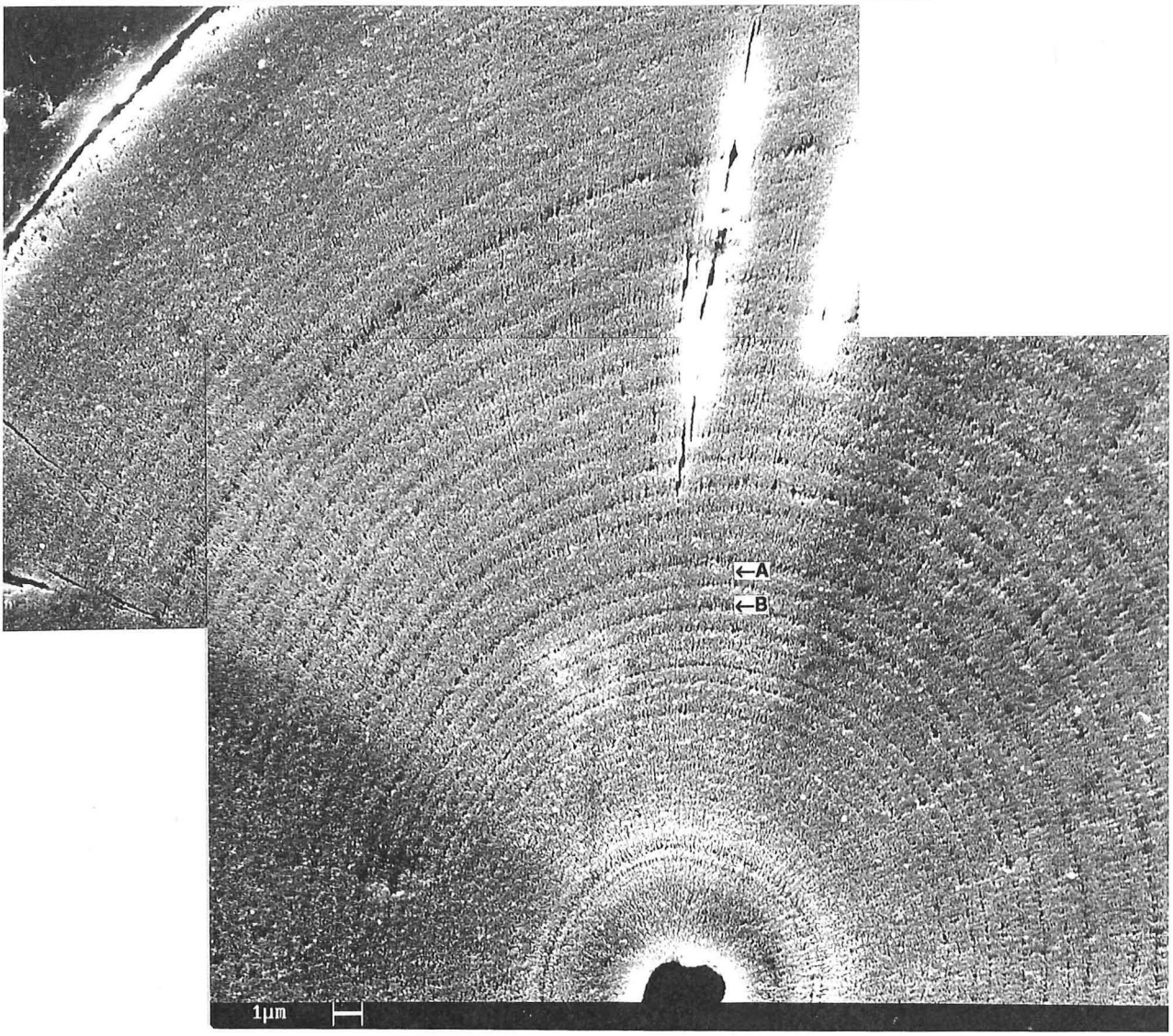


Plate A.4. View of the same scorpionfish (*Scorpaena papillosus*) otolith using bright field microscopy. Arrows indicate the position of fluorescent markings. The number of increments between the marks was c. 30.



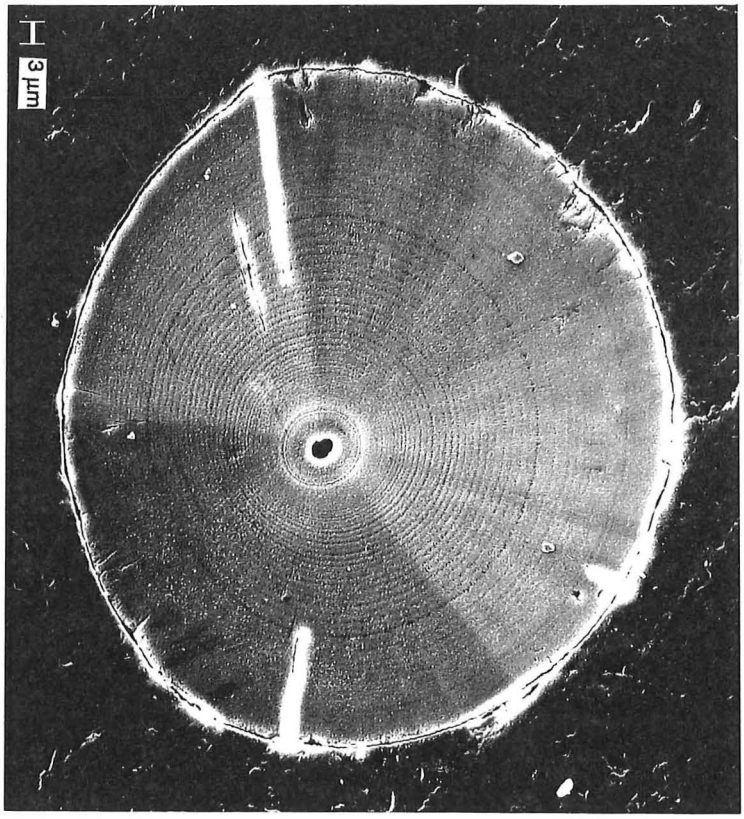


Plate A.5. Otolith from a 23.2 mm TL larval smelt (*Stokellia anisodon*) at high power (4000x) (montage) and low power (860x) using the scanning electron microscope. The primordium has fallen out during preparation (central region). Increments are again bipartite with an incremental zone (A) and a discontinuous zone (B).

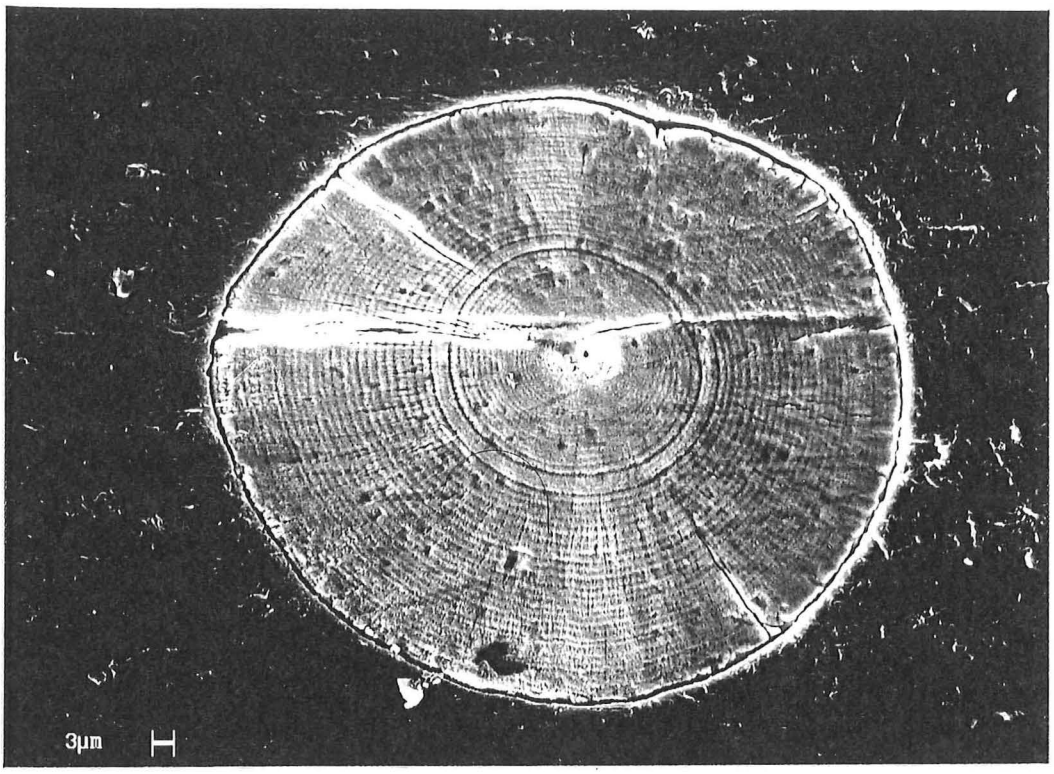


Plate A.6. Low power (920x) micrograph using the scanning electron microscope of a smelt (*Stokellia anisodon*) otolith showing growth increments (arrow). Increment counts were obtained by counting from the innermost increment, visible at high power, and counting each dark ring (discontinuous zone) present outside of this increment.

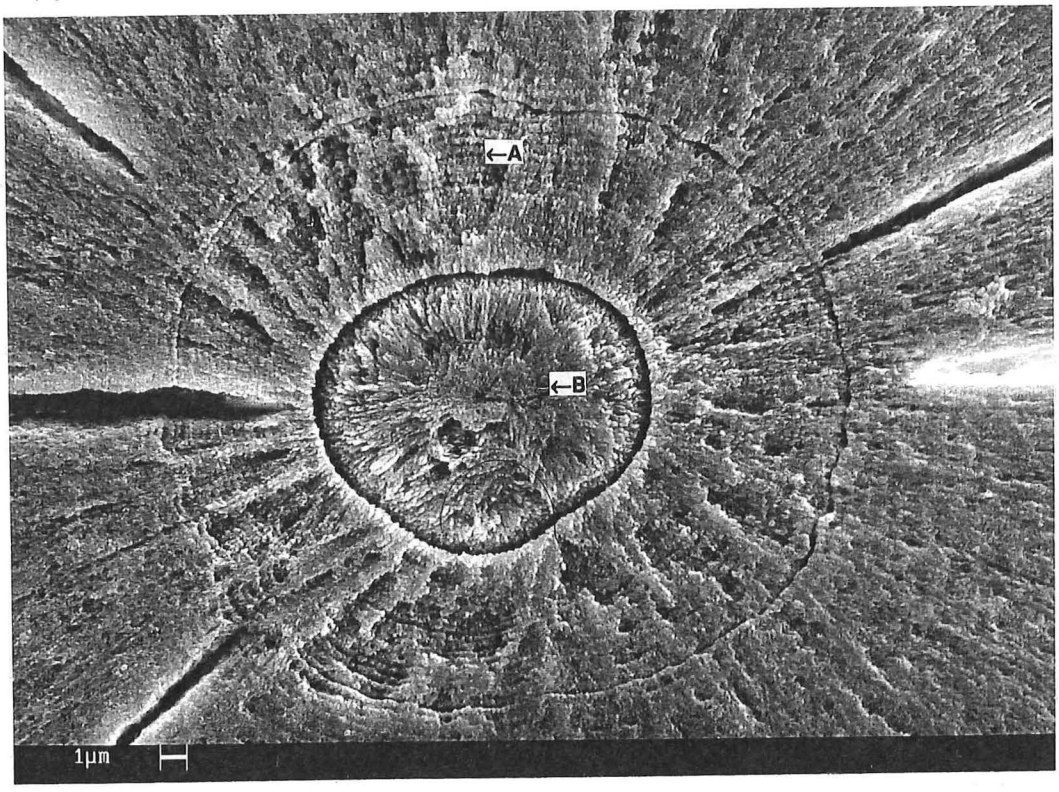


Plate A.7. High power (3500x) view of central part of a flounder (*Rhombosolea plebeia*) otolith using the scanning electron microscope showing many fine inner growth increments (A) and the structure of the primordium (B). The outer region is not readable.

Validation Experiments

i) Marking Otoliths with Tetracycline

No fluorescent marks were found in any of the otoliths of the pre-juvenile triplefins (*Forsterygion lapillum*). Also, no fluorescent mark was present in the spotty (*Notolabrus celidotus*) otolith, but there was a distinctive increment which was optically different than the surrounding increments (Plate A.2). There were 10 increments between this distinctive increment and the otolith margin.

ii) Marking Otoliths by Manipulating Photoperiod

No differences in increment widths were visible anywhere near the margin of the larval pigfish's (*Congiopodus coriaceus*) otolith.

iii) Labelling Otoliths With Strontium Chloride

There was no strontium peak detected on the x-ray spectrum at the energy keV value of 14.1. The strontium x-ray map did not reveal the presence of strontium either.

iv) Marking Otoliths With Alizarin Complexone

- Stokell's Smelt (*Stokellia anisodon*)

No fluorescent marks were observed in the otoliths of any of the three smelts that were immersed in the alizarin complexone solution.

- Scorpionfish (*Scorpaena cardinalis*)

Two bands of fluorescence were present in the otoliths of the scorpionfish pre-juveniles which had been immersed in alizarin complexone (Plate A.3). The control specimen did not have any fluorescent markings.

The number of increments observed between these two fluorescent bands was approximately 30 (Plate A.4). If these increments are deposited daily then only 10 increments would be expected between these two fluorescent bands.

Many otoliths that were prepared for viewing with the scanning electron microscope gave poor results and no counts could be made of the otolith increments. These included otoliths from *Congiopodus coriaceus*, *Rhombosolea plebeia*, *Gaidropsarus novaezelandiae*, and *Notolabrus celidotus*.

Age at length estimates

- Stokell's Smelt (*Stokellia anisodon*)

Table A.1 Mean number of dark rings in otoliths from Stokell's smelt larvae using two microscope techniques

Total Length (mm)	Light Microscope	Scanning Electron Microscope
9.0	23	
9.7	22	
10.5	25	
13.8	32.7	
15.8	39	30
18.0	46	
21.5	44.3	56
23.2	57	57
25.3	57.7	60
27.3	80	
27.7	76	
31.6	88	
34.2	102	

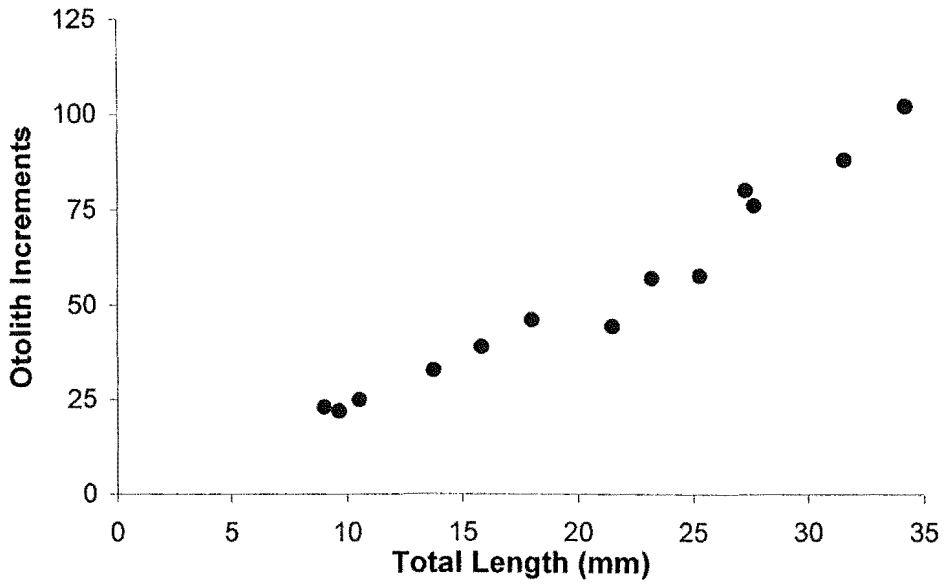


Figure A.1 Number of dark rings in otoliths from Stokell's smelt larvae of different lengths (light microscope data).

- *Diaphus* sp.

Table A.2 Mean number of dark rings in otoliths from *Diaphus* sp. larvae using two microscope techniques

Total Length (mm)	Light Microscope	Scanning Electron Microscope
9.7	32.3	
13	48	52
18.8	77	

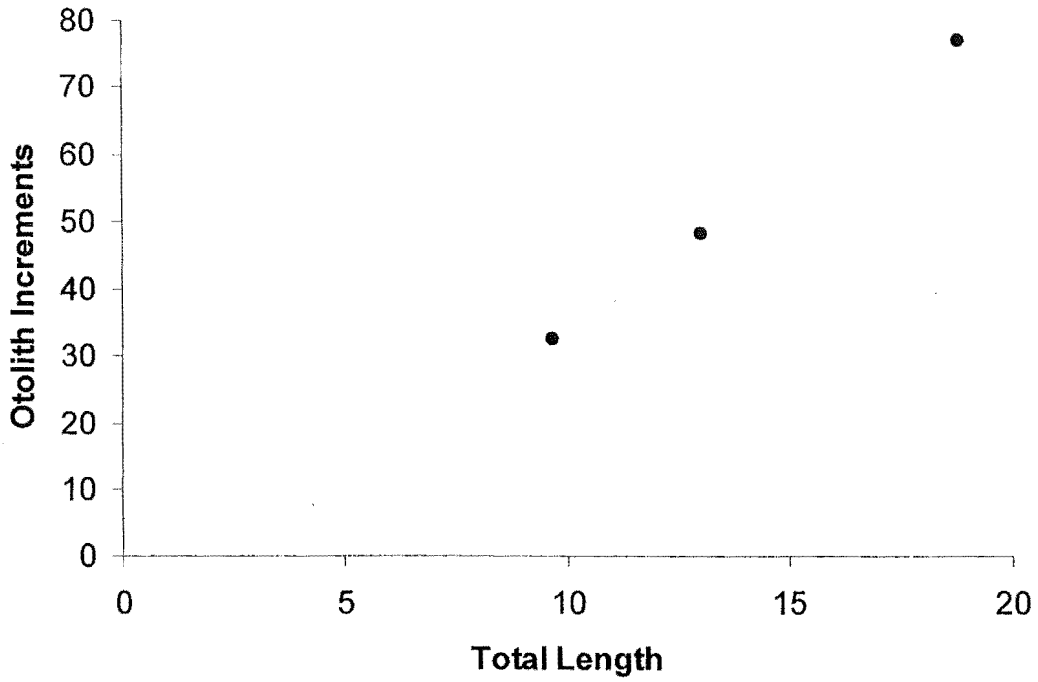


Figure A.2 Number of dark rings in otoliths from *Diaphus* sp. larvae of different lengths (light microscope data).

- Rockling (*Gaidropsarus novaezelandiae*)

Table A.3 Mean number of dark rings in otoliths from rockling larvae using light microscopy

Total Length (mm)	Increments
9.4	68
29	137

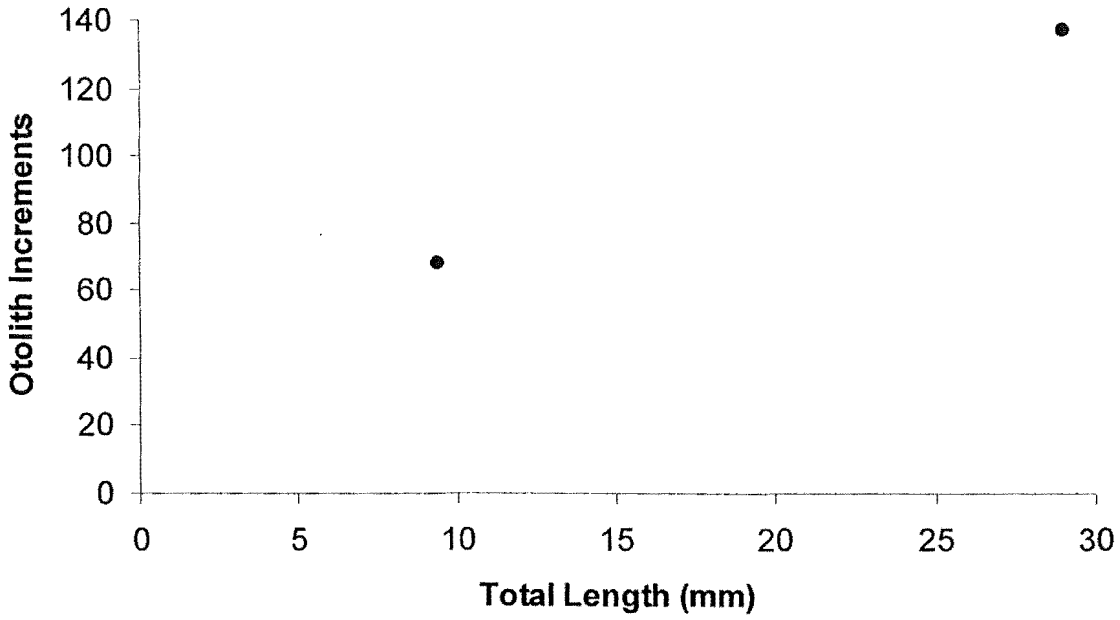


Figure A.3 Mean number of dark rings in otoliths from rockling larvae of two different lengths.

- Yellow-Eyed Mullet (*Aldrichetta forsteri*)

Table A.4 Mean number of dark rings in otoliths from yellow-eyed mullet larvae using light microscopy

Total Length (mm)	Increments
6.0	28
9.0	45.7
12.8	64
13.8	65.3
16.3	85

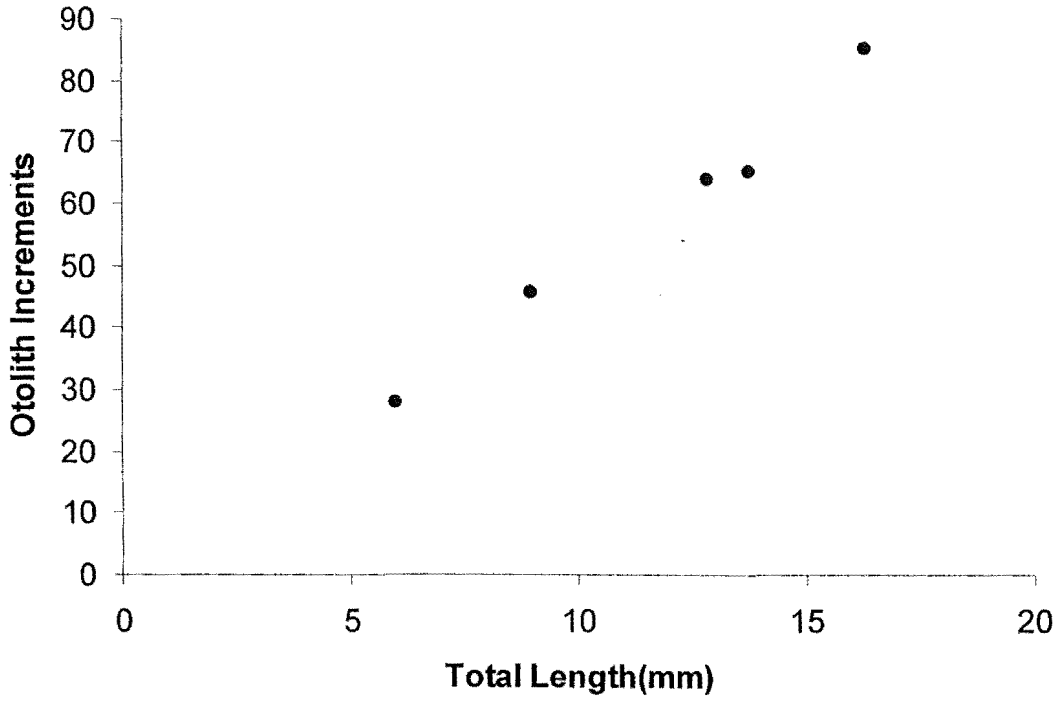


Figure A.4 Mean number of dark rings in otoliths from yellow-eyed mullet larvae of different lengths.

DISCUSSION

The aim of this work was to provide rates of otolith increment deposition and age-at-length estimates for several species of larval fishes. Most methods used to mark otoliths to investigate rates of otolith increment formation did not successfully mark the otoliths of the species tested. The exceptions to this were alizarin complexone immersion for scorpionfish (*Scorpaena papillosus*) and osmotic shock and immersion in tetracycline for spotties (*Notolabrus celidotus*). However, the same method of immersion in alizarin complexone failed to mark otoliths of Stokell's smelt (*Stokellia anisodon*) larvae. This suggests that species-specific differences may exist in the response to immersion in marker dyes and that more work is required to ascertain the most appropriate methodology for each species of interest.

The rate of increment formation for scorpionfish was found to be non-daily, with approximately three increments formed per day over a 10 day period of captivity. These pre-juveniles were fed three times per day and it may be that the sub-daily increments reflect the frequency of feeding while in captivity, rather than an intrinsic rate of increment formation. Wild larvae are more likely to have a continuous supply of food, and the possibility of wild larvae having daily increments is not discounted. Also, the effects of handling stress and immersion in toxic marker dyes may have altered the metabolism of the experimental specimens.

The results for spotty (*Notolabrus celidotus*) larvae, based on a single specimen, is suggestive of daily increment formation. However, the otolith did not show a fluorescent mark at the expected location and so this is based on a purely subjective analysis of the appearance of the increment at the expected position of the fluorescent marker.

Methodology for counting increments is also important. Counts of increments made using a compound light microscope at 1000x magnification were not always closely similar to counts made using a scanning electron microscope. Usually any difference in light microscope counts and scanning electron microscope counts is the result of increments that are too fine to be resolved using light microscopy but being counted using the scanning electron microscope. This resulted in generally higher counts when using the scanning

electron microscope. However, the scanning electron microscope counts for one otolith were much lower than those obtained using the light microscope (Table A.1). This may have occurred in two ways. Firstly, it could be that the otolith was sectioned at exactly the mid-plane when counts were made with the light microscope. Further polishing during preparation for scanning electron microscopy may have removed some of the fine inner rings resulting in a lower count. Alternatively, the etching process using EDTA may have destroyed some of the very fine inner rings but not the coarser outer rings. It may be necessary to fine-tune etching times to allow for differences in otolith composition between species. Light microscopy was used most often as otoliths could be processed more quickly and results were generally more consistent within a species.

Age-at-length estimates cannot be reliably made unless the rate of increment formation for a species is known. Since this remains unknown for most species investigated in this study, any age-at-length estimates made must assume an increment formation rate. The most likely rate is probably daily since c. 17 out of 20 larval fish species from around the world have been reported as having daily increment formation rates (Jones, 1986).

The low number of samples processed also limits the usefulness of age-at-length estimates in this work (particularly for *Gaidropsarus novaezelandiae* and *Diaphus* sp.) (Figs. A.1 - A.4).

Using otoliths to age wild-caught larvae remains a potentially useful tool. However, learning appropriate methodology is a trial-and-error affair for each species being investigated and is a very time-consuming process. Logistical constraints on time limited the number of otoliths that could be processed for this study once suitable equipment had been obtained for the work involved. Future study should address the possible influence of experimental conditions (e.g. feeding regimes, handling stress, toxicity of dye markers) on otolith growth.

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Acanthoclinus fuscus	Elder (1966), Jillet (1968a,b), Frentzos (1980), Crossland (1981, 1982), Roper (1981), Kingsford & Barrington (1986), Dolphin (1997)
Aldrichetta forsteri	Crossland (1981), Cassie (1955), Maniakim (1963), Robertson (1975), Kingsford & Barrington (1986), Dolphin (1997)
Alertichthys blacki	Robertson & Mito (1979)
Allomycterus jaculiferus	Robertson (1975), Crossland (1982)
Argentina elongata (eggs only)	Robertson (1975)
Arnoglossus scapha	Robertson (1973, 1975), Dolphin (1997)
Arripis trutta (eggs only)	Robertson (1975)
Auchenoceros punctatus	Robertson (1973, 1975), Frentzos (1980), Crossland (1981), Roper (1981) Thompson (1983), Kingsford & Barrington (1986), Dolphin (1997)
Bathylagus sp.	Robertson (1973)
Bovichtus variegatus	Robertson & Mito (1979), Dolphin (1997)
Caranx georgianus	Robertson (1975), James (1976), Kingsford & Barrington (1986)
Cepola aotea	Roper (1981), Kingsford & Barrington (1986)
Cheilodactylus spectabilis	
Chelidonichthys kumu	Anderton (1906), Thomson & Anderton (1921), Mito (1963), Robertson (1973, 1975), Roper (1981), Kingsford & Barrington (1986), Dolphin (1997)
Chromis dispilis	Kingsford (1981), Roper (1981), Kingsford & Barrington (1986)
Coelorhynchus aspercephalus (eggs only)	Robertson (1975)
Coelorhynchus australis (eggs only)	Robertson (1975)
Colistium guntheri	Thomson & Anderton (1921)?, Robertson (1975), Graham (1956), Dolphin (1997)

Colistium nudipinnis (eggs only)	Anderton (1906), Thomson & Anderton (1921), Robertson (1975)
Cologrammus flavescens	Ruck (1976)
Congiopodus leucopaecilus	Thomson & Anderton (1921), Robertson (1973, 1974, 1975)
Congiopodus coriaceus	Dolphin (1997)
Crapatalus angusticeps (eggs only)	Robertson (1975)
Cyclothone sp.	Robertson (1973)
Dellichthys morelandi	Elder (1966), Frentzos (1980), Roper (1981), Kingsford & Barrington (1986)
Diaphus sp.	Regan (1916)
Diaphus sp.	Dolphin (1997)
Diplocrepis puniceus	Ruck (1973a, 1976), Frentzos (1980), Thompson (1983), Kingsford & Barrington (1986)
Diplophos rebainsi	Robertson (1973)
Echiodon cryomargarites	Markle & Olney (1990)
Echiodon pegasus	Dolphin (1997)
Echiodon rendahli	Markle & Olney (1990)
Engraulis australis	Elder (1966), Baker (1972), Robertson (1975) Frentzos (1980), Crossland (1981, 1982), Thompson (1983), Kingsford & Barrington (1986), Cole (1987)
Eurypleuron owasianum	Robertson (1975a, b)
Forsterygion lapillum	Ruck (1973b, 1976), Kingsford & Barrington (1986), Dolphin (1997)
Forsterygion nigripenne	Ruck (1973b, 1976), Frentzos (1980), Kingsford & Barrington (1986)
Forsterygion varium	Ruck (1976, 1980), Roper (1981), Kingsford & Barrington (1986),
Gaidropsarus novaezelandiae	Robertson & Mito (1979), Dolphin (1997)
Galaxias brevipinnis	McDowall & Suren (1995)
Galaxias fasciatus	Mitchell (1991)

Galaxias maculatus	McDowall (1970), Mitchell (1989, 1991), Kingsford & Barrington (1986)
Gastroscyathus gracilis	Ruck (1976)
Gastroscyathus hectoris	Ruck (1976), Frentzos (1980)
Genyagnus monopterygius	Robertson (1975), Crossland (1981, 1982), Kingsford & Barrington (1986), Dolphin (1997)
Gilloblennius tripennis	Ruck (1976, 1980), Frentzos (1980), Thompson (1983), Kingsford & Barrington (1986), Dolphin (1997)
Girella tricuspidata	Munro (1945), Kingsford & Barrington (1986)
Gnathophis habenatus	Castle (1963), Robertson (1975), Castle & Robertson (1974), Kingsford & Barrington (1986)
Gnathophis incognitus	Castle (1963), Robertson (1975), Castle & Robertson (1974), Kingsford & Barrington (1986)
Gobiomorphus huttoni	McDowall (1965), Kingsford & Barrington (1986)
Gobiopsis atrata	Dolphin (1997)
Grahamichthys radiata	Elder (1966), Robertson (1973), Frentzos (1980), Crossland (1981, 1982), Kingsford & Barrington (1986), Dolphin (1997)
Grahamina capito	Dolphin (1997)
Grahamina signata	Dolphin (1997)
Gymnoscopelus piabilis	Robertson & Mito (1979), Dolphin (1997)
Gymnothorax prasinus	Crossland (1981), Kingsford & Barrington (1986)
Helcogramma sp. 1 (?)	Ruck (1976)
Helcogramma sp. 2 (?)	Ruck (1976)
Helcogramma medium (?)	Ruck (1976)
Helicolenus percoides	Thomson & Anderton (1921), Graham (1939, 1956), Elder (1966), Crossland (1982)
Helicolenus barathri	Dolphin (1997)

Hemerocoetes monopterygius	Frentzos (1980), Roper (1981), Kingsford & Barrington (1986)
Hippocampus abdominalis	Graham (1939, 1956), Elder (1966), Frentzos (1980), Kingsford & Barrington (1986), Dolphin (1997)
Hoplichthys haswelli	Robertson (1973, 1975)
Hyporhamphus ihi	Graham (1939, 1956), Crossland (1981), Roper (1981), Kingsford & Barrington (1986)
Kathetostoma giganteum (eggs only)	Robertson (1975)
Lampanyctus steinbecki (eggs only)	Robertson (1975)
Lampmyctodes hectoris	Robertson (1973)
Lastidiops jayakaripacificum	Robertson (1973)
Lepidopus caudatus	Regan (1916), Robertson (1973, 1975, 1980)
Lepidoperca sp A.	Robertson (1975), Dolphin (1997)
Leptonotus elevatus	Dolphin (1997)
Limnichthys rendahli	Robertson (1973), Kingsford & Barrington (1986)
Lissocampus filum	Elder (1966), Frentzos (1980), Roper (1981), Kingsford & Barrington (1986)
Lophonectes gallus	Robertson (1973), Crossland (1981, 1982), Thompson (1983), Kingsford & Barrington (1986)
Maurolicus muelleri	Robertson (1975, 1976)
Mendosoma lineatum	Robertson (1975), Crossland (1981), Dolphin (1997)
Mugil cephalus	Robertson (1975), Crossland (1981), Kingsford & Barrington (1986)
Nemadactylus douglasi (eggs only)	Robertson (1975)
Nemadactylus macropterus	Robertson (1973, 1975), Kingsford & Barrington (1986)
Notoclinus compressus	Ruck (1976)
Notoclinus fenestratus	Ruck (1976), Dolphin (1997)

Notolabrus celidotus	Elder (1966), Robertson (1973, 1975) Frentzos (1980), Jones (1980), Crossland (1981), Roper (1981), Thompson (1983), Duffy (1989), Dolphin (1997)
Notolabrus fucicola	Robertson (1973, 1975)
Notopogon lillei (eggs only)	Robertson (1975)
Odax pullus	Ritchie (1969), Robertson (1975), Kingsford & Barrington (1986), Dolphin (1997)
Optivus elongatus	Crossland (1981), Kingsford & Barrington (1986)
Pagrus auratus	Cassie (1955, 1956), Robertson (1975),Crossland (1980, 1981, 1982), Roper (1981), Kingsford & Barrington (1986), Kingsford & Atkinson (1994), Francis (1994), Pankhurst (1994), Pankhurst et al. (1991), Scott & Pankhurst 1992),
Paranotothenia microlepidoptera (eggs only)	Robertson (1975)
Parapercis colias	Anderton (1906), Thomson & Anderton (1921), Robertson (1973, 1975), Kingsford & Barrington (1986), Dolphin (1997)
Parapercis gilliesi	Robertson (1975)
Paratrachichthys trailli	Robertson (1975), Dolphin (1997)
Parika scaber	Regan (1916), Elder (1966), Robertson (1975), Crossland (1981, 1982), Roper (1981), Kingsford & Choat (1985), Kingsford & Milicich (1987), Dolphin (1997)
Pelotretis flavilatus	Thomson & Anderton (1921), Rapson (1940), Robertson (1975), Roper (1981), Kingsford & Barrington (1986)
Peltorhamphus latus	Roper (1979), Frentzos (1980), Crossland (1981, 1982), Roper (1981), Kingsford & Barrington (1986)

Peltorhamphus novaezelandiae	Thomson & Anderton (1921), Robertson (1973, 1975), Kingsford & Barrington (1986), Dolphin (1997)
Peltorhamphus tenuis (eggs only)	Robertson (1975)
Pseudophycis bacchus	Robertson (1975), Dolphin (1997)
Pterygotrigla picta (eggs only)	Robertson (1975)
Regalecus glesne (eggs only)	Robertson (1975)
Rhombosolea leporina	Robertson (1975), Crossland (1981, 1982), Roper (1979, 1981), Kingsford & Barrington (1986)
Rhombosolea plebeia	Thomson & Anderton (1921), Robertson & Raj (1971), Kilner (1974), Robertson (1975), Roper (1979, 1981), Kingsford & Barrington (1986), Dolphin (1997)
Rhombosolea retiaria	Roper (1979), Eldon & Smith (1986), Dolphin (1997)
Ruanoho decemdigitatus	Ruck (1976, 1980), Frentzos (1980), Thompson (1983), Kingsford & Barrington (1986), Dolphin (1997)
Sardinops neopilchardus	Regan (1916), Baker(1972), Elder (1966), Robertson (1975), Kingsford & Barrington (1986), Cole (1987)
Scomber australasicus	Crossland (1981, 1982), Kingsford & Barrington (1986)
Scomberesox saurus (?) (eggs only)	Robertson (1975)
Scorpaena cardinalis	Elder (1966), Robertson (1973), Kingsford & Barrington (1986)
Scorpaena papillosus	Dolphin (1997)
Seriolella brama	Robertson (1975), Frentzos (1980), McDowall (1980)
Seriolella caerulea	McDowall (1980), Dolphin (1997)
Seriolella punctata	Robertson (1975), McDowall (1980), Grimes & Robertson (1981)

Snyderidia canina	Markle & Olney (1990)
Spheroides richei (?)	Elder (1966)
Sprattus antipodum	Baker (1972, 1973), Robertson (1975), Frentzos (1980), Crossland (1981, 1982), Thompson (1983), Kingsford & Barrington (1986)
Sprattus muelleri	Dolphin (1997)
Stigmalophora macropterygia	Elder (1966), Roper (1981), Kingsford & Barrington (1986)
Stokellia anisodon	Dolphin (1997)
Symbolophorus boops	Robertson (1973)
Taumakoides rua	Dolphin (1997) (possibly Frentzos (1980), Crossland (1981, 1982))
Tewara cranwellae	Roper (1981), Kingsford & Barrington (1986)
Thyrsites atun	Regan (1916), Haigh (1972), Robertson (1975), Robertson & Mito (1979), Crossland (1982), Kingsford & Barrington (1986), Dolphin (1997)
Trachelochismus melobesia	Elder (1966), Ruck (1971, 1976), Frentzos (1980), Thompson (1983), Kingsford & Barrington (1986), Dolphin (1997)
Trachelochismus pinnulatus	Elder (1966), Ruck (1973a, 1976), Frentzos (1980), Roper (1981), Thompson (1983), Kingsford & Barrington (1986)
Trachurus declivis (eggs only)	Robertson (1975), Crossland (1981)
Trachurus mccullochi (?) (eggs only)	Robertson (1975)
Trachurus novaezelandiae	Crossland (1981), Roper (1981), Kingsford & Barrington (1986)
Zenopsis nebulosus (eggs only)	Robertson (1975)
Zeus faber	Russell (1976), Kingsford & Barrington (1986)

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UNIDENTIFIED SPECIES 1.

Collected in South Bay on 21/12/91 using a hand-held dipnet @ 1m below the surface. Reference Collection P.

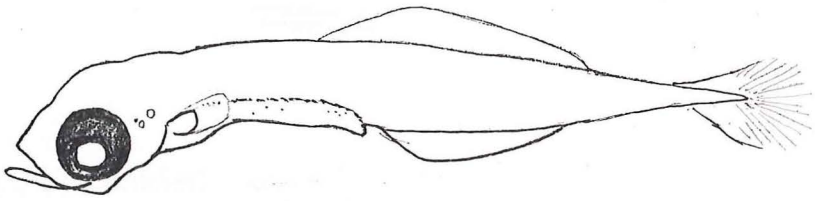

Figure D.1 Unidentified Species 1 (4.0 mm TL)

UNIDENTIFIED SPECIES 2.

Collected in South Bay on 24/11/95 in plankton tow @ 3m below the surface. Reference collection N.

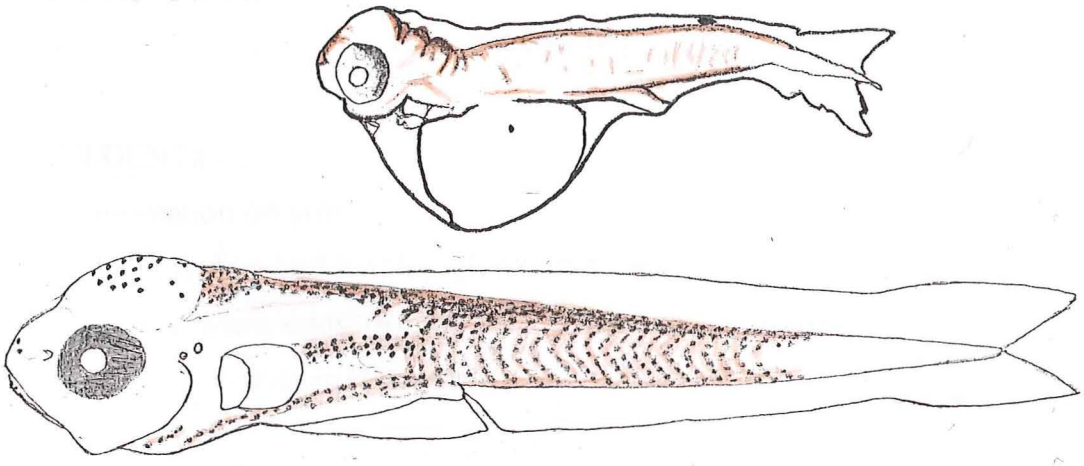

Figure D.2 Unidentified species 2.

a) 3.0 mm TL

b) 4.8 mm TL

UNIDENTIFIED SPECIES 3.

Collected from surface plankton tows at the 6 km site on 24/7/96. Similar to *Bovichtus variegatus* larvae but more elongate. Reference Collection AP.

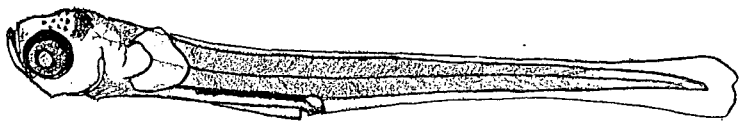

Figure D.3 Unidentified species 3. (8.2 mm TL)

Some eggs were collected in this study near the end of November, 1996, in daylight plankton tows one meter below the water surface. These eggs were from several species and most were in the size range 0.7 - 0.85 mm diameter. They all had a single oil droplet of .13 - 0.18 mm diameter. The eggs were highly abundant at the 2km site as well as in South Bay. All eggs had well advanced embryos present at capture and most hatched within 30 hours. Attempts to rear the larvae that hatched out from these eggs were unsuccessful. The following larvae were all hatched out from these eggs.

UNIDENTIFIED SPECIES 4.

Pigmentation on yolk sac larvae is yellow and black. Yellow pigment reduces as larvae develop and black pigmentation increases. Eggs very closely similar to banded wrasse eggs (Robertson, 1975) but oil droplet is posterior in yolk-sac larvae (cf. anterior in Robertson (1973)). Reference collection BE.

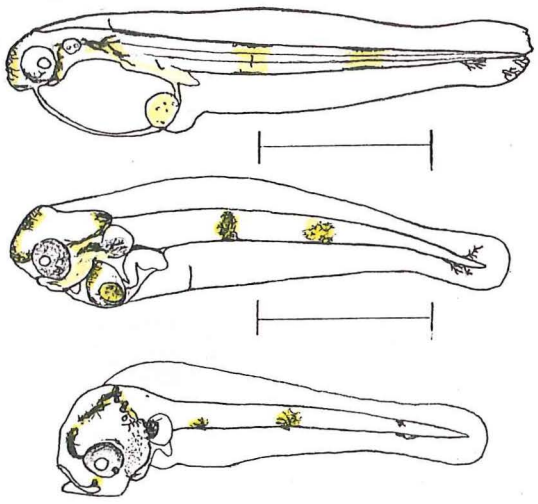

Figure D.4 Unidentified species 4.
(scale=1mm)

UNIDENTIFIED SPECIES 5.

Pigmentation is mainly orange with some fine melanophores along the ventral midline of the body. A large lateral melanophore develops half way between the anus and notochord tip. Size at hatching is c. 3.4 mm TL. Possibly may be a labrid. Reference Collection BH.

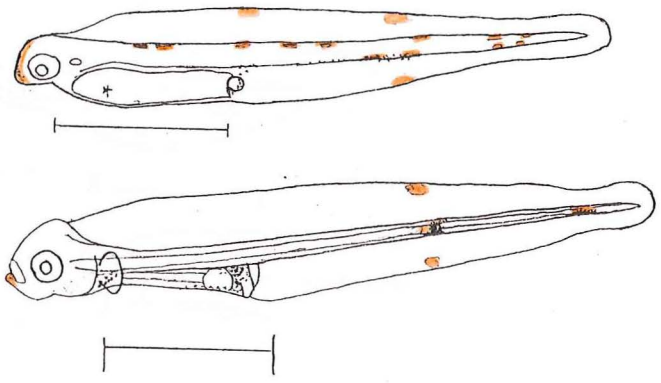

Figure D.5 Unidentified species 5.
a) 3.4 mm TL
b) 3.8 mm TL
(scale = 1mm)

UNIDENTIFIED SPECIES 6.

Very distinctive larva with extensive white stellate pigmentation present across the body and dorsal and anal finfolds.

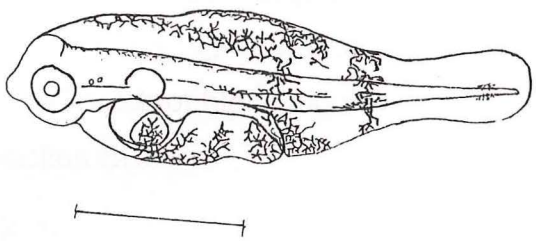

Figure D.6 Unidentified species 6 (3.1 mm TL)
(scale = 1mm)

UNIDENTIFIED SPECIES 7.

Size at hatching c. 3.5 mm TL. Reddish-orange pigment with black melanophores in two distinct areas: immediately above the gut, and on the dorsal contour behind the anus. A less distinct patch is also present behind the anus on the ventral contour of the body. Black pigmentation is also present on the head. Some larvae developed a small white patch on the dorsal finfold two days after hatching. Reference collection BO.

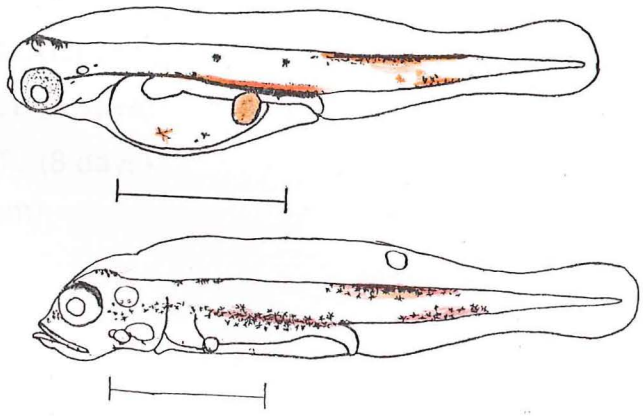

Figure D.7 Unidentified species 7.
a) 3.5 mm TL
b) 3.9 mm TL
(scale = 1mm)

UNIDENTIFIED SPECIES 8.

Size at hatching c. 2.9 mm TL. Oil droplet position is anterior in yolk-sac. Yellow pigment is present on dorsal and ventral body contours at the anus. Also present around anterior part of yolk-sac prior to resorption. Black pigmentation present on the cranium and in patches along the dorsal body contour. Several small melanophores present along ventral midline as larvae develop. During development further black pigmentation appears on the dorsal finfold and at the anus. Also, a small patch of black pigment develops at the tip of the lower jaw. Reference collection BR.

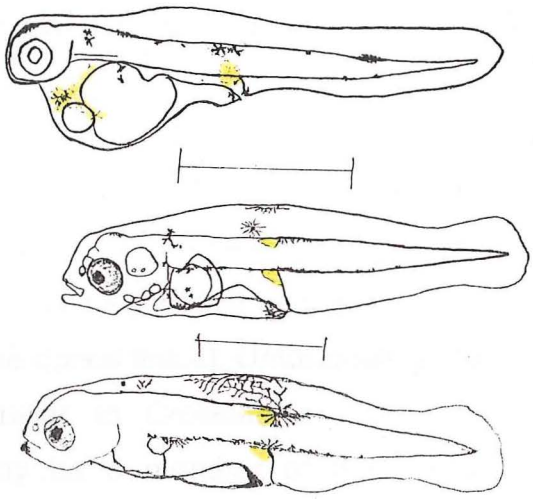

Figure D.8 Unidentified species 8.

a) 2.9 mm TL (hatching)

b) 3.8 mm TL (4 days)

c) 3.6 mm TL (8 days)

(scale = 1 mm)

UNIDENTIFIED SPECIES 9.

This was the most common species which hatched from the egg assortment. Size at hatching is c. 2.35 mm TL. Yellow pigment is present around the eyes and in patches along the body. As the larvae develop, the yellow pigmentation steadily reduces, with no trace being left after 6 days. Tiny melanophores in the yolk-sac larvae increase in number and size around the gut and anus. A large stellate melanophore, centred on the ventral midline, is present between the anus and notochord tip. After 6 days, small patches of black pigment are present on the angle of the jaw and immediately in front of the anus. Pelvic fin buds appear at 9 days. The lower jaw is beginning to project at this stage of development. At 13 days the pelvic fins are much larger and are heavily pigmented with black melanophores. Cephalic spines are beginning to appear at the margin of the pre-operculum. These do not conform to the scorpaenid patterns of Moser *et al.* (1977) or those observed for scorpaenid larvae in this study. After 16 days the pelvic fins are prominent and most heavily pigmented towards the ends. The preopercular spines are beginning to become pigmented. The most significant change is the formation of a heavily pigmented protrusion of the dorsal finfold. Unfortunately, no larvae survived past this point. These are similar to Crossland's (1982) unidentified larva 2 which he considered may be a member of the serranid subfamily anthiinae. Local serranid species are *Caesioperca lepidoptera*, *Callanthias allporti*, *Ellerkeldia huntii* and *Lepidoperca* sp. A (Edward Percival Field Station teleost species record).

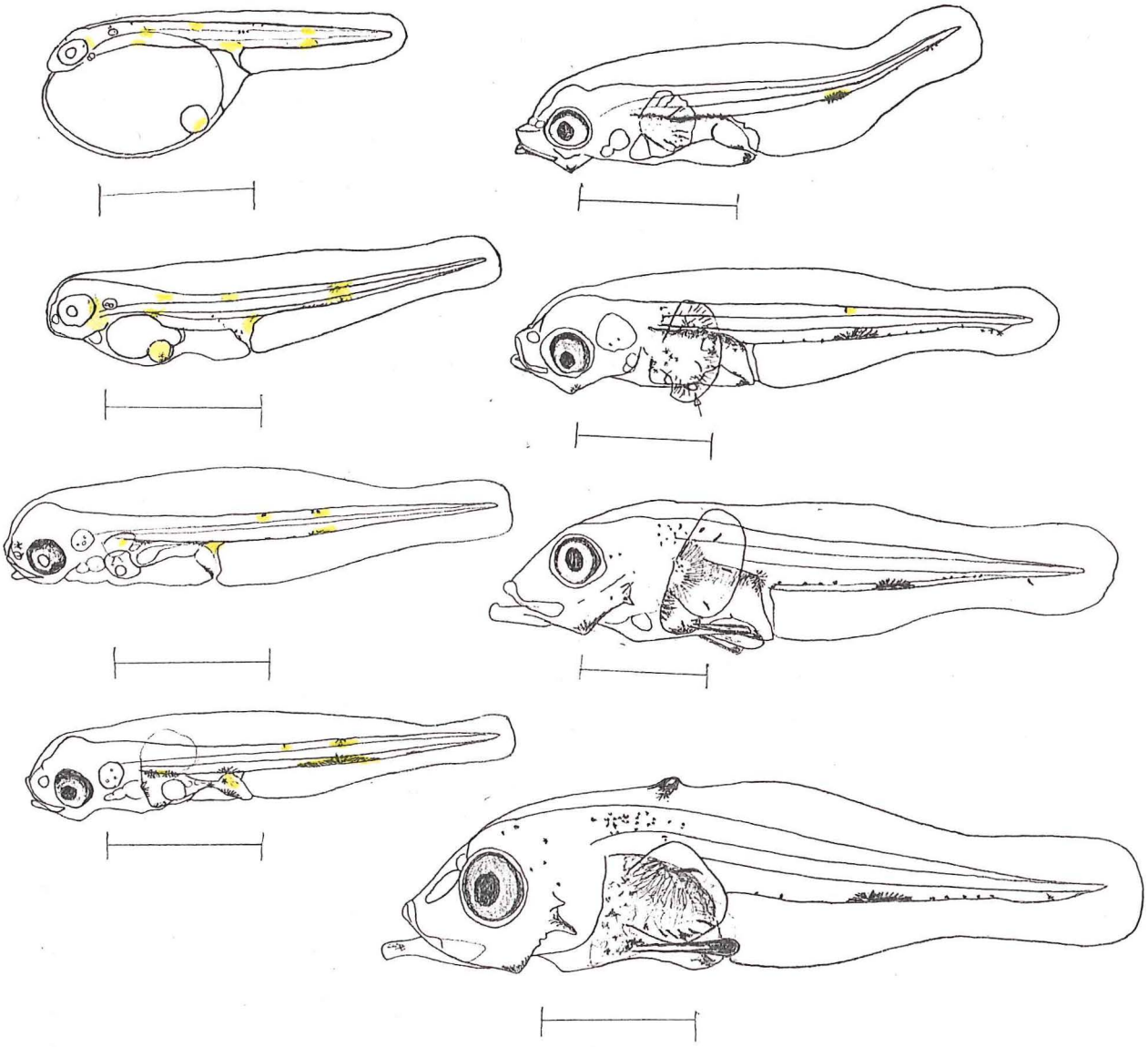

Figure D.9 Unidentified species 9. (scale = 1 mm)

a) 3.36 mm TL (hatching)
b) 2.71 mm TL (2 days)
c) 3.29 mm TL (4 days)
d) 3.18 mm TL (5 days)
d) 3.41 mm TL (6 days)
e) 4.05 mm TL (9 days)
f) 4.88 mm TL (13 days)
g) 4.86 mm TL (16 days)